Historic, Archive Document

Do not assume content reflects current scientific knowledge, policies, or practices.

189

United States
Department of
Agriculture

Forest Service

Forest Pest
Management

Davis, CA

FSCBG MODEL COMPARISONS WITH THE 1988 DAVIS SPRAY CHARACTERIZATION TRIALS

FPM 93-12
August 1993

Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.

FPM 93-12
C. D. I. Technical Note No. 93-08
August 1993

FSCBG MODEL COMPARISONS WITH THE 1988 DAVIS SPRAY CHARACTERIZATION TRIALS

Prepared by:

Alina Z. MacNichol

Milton E. Teske

Continuum Dynamics, Inc.
P. O. Box 3073
Princeton, NJ 08543

Contract No. 53-0343-1-00153

Prepared for:

USDA Forest Service
Forest Pest Management
2121C Second Street, Suite 102
Davis, CA 95616

John W. Barry
Project Officer

Summary

This paper describes FSCBG simulations for the aerial application of four formulations of Bacillus thuringiensis from two aircraft configured with three types of rotary atomizers. Forty-four trials for ultra-low volume applications were performed by the USDA Forest Service in March 1988 at a test site near Davis, California. Deposition (defined in drops per square centimeter) and swath width determined during analysis of the field test data is compared to FSCBG simulations of ground deposition for each of the forty-four trials. Despite some uncertainty as to the drop size spectra of the Bt formulations used, average correlation of FSCBG predictions to the field data is $R^2=0.65$ for drops. Swath width is also predicted well ($R^2=0.66$). Wind tunnel testing is recommended to expand the database of drop size spectra to include more Bt formulations and nozzle types currently in use by the USDA Forest Service, and also to extend the existing database to drops below 34 micrometers in size.

Table of Contents

1. Introduction

This paper is the second of a series of validation studies to be accomplished in 1993-1994 for the Forest Service Cramer-Barry-Grim (FSCBG) aerial spray model (Teske et al. 1993) and its near-wake Agricultural Dispersal (AGDISP) model (Bilanin et al. 1989). Field tests of several different aerial spray pesticides have been performed with a variety of aircraft. Ground deposition data from each of these tests is available for comparison with FSCBG and AGDISP simulations. This paper is concerned with a test performed in March 1988 to observe the atomization of undiluted formulations of Bacillus thuringiensis in rotary atomizers placed on two different aircraft. It follows the format of our previous report (MacNichol and Teske 1993).

The USDA Forest Service in cooperation with the United States Army has developed FSCBG incorporating AGDISP as its near-wake model. FSCBG predicts the transport and behavior of pesticide sprays released from aircraft, influenced by the aircraft wake and local atmospheric conditions, through downwind drift and deposition to total accountancy and environmental fate. The AGDISP near-wake representation solves a Lagrangian system of equations for the position and position variance of material released from each nozzle on the aircraft. The FSCBG far-wake representation begins with the results of AGDISP at the top of a canopy or near the ground, and solves a Gaussian diffusion equation to recover ground deposition. FSCBG includes an analytic dispersion model for multiple line sources oriented in any direction to the wind, an evaporation model for volatile spray components, a canopy penetration model for forest canopy interception, and an accountancy model to recover environmental fate of released material.

Drop size distributions give the mass distribution of material as it is atomized by each nozzle. Drops containing volatile material (such as water) begin to evaporate immediately upon entering the atmosphere, with the local temperature, relative humidity and relative wind speed determining the evaporation rate. The presence of the aircraft wake (with its vortical structure) may move material to unanticipated locations. Ambient winds superimpose additional horizontal velocity vectors on the spray material. Canopy deposition removes spray material from the air and prevents nonvolatile components from reaching the ground. Every aspect of the spray process is affected by the size and significance of atmospheric and aircraft-generated turbulence.

Meteorological calculations generate the background wind speed, temperature and relative humidity profiles. Evaporation calculations track the time rate of decrease of drop size. Canopy calculations remove additional material through impaction on vegetation. Near-wake calculations follow the behavior of released spray near the aircraft, and when out of wake influence or at the top of the canopy, hand off to the dispersion calculations to predict the dosage, concentration and deposition at user-designated downwind locations.

Technical aspects of the FSCBG model are discussed in Teske et al. (1993). Comparisons with data include downslope drift in open terrain (Barry et al. 1993), a drift study over desert (Boyle et al. 1975), canopy penetration in Southern pine (Rafferty et al. 1982), open terrain and canopy penetration in Douglas-fir (Teske et al. 1991), eastern oak (Anderson et al. 1992), and Gambel oak (Rafferty and Grim 1992).

The aircraft spray characterization trials referred to in this paper took place from March 14 to March 19, 1988 at Growers Air Service, Woodland, California. The USDA Forest Service (FS), Forest Pest Management, performed forty-four trials for ultra-low

volume (ULV) applications in preparation for the FS 1988 operational program to control western spruce budworm in Oregon. The major objectives were to identify potential problems in the spraying and atomization of the Bt formulations tested and to compare sampling procedures on different Kromekote card positions relative to the spray application. This paper is concerned only with the deposition data collected from cards at ground level.

Deposition data and meteorological data from the trials were summarized and analyzed by Steinke and Silva (1992). Deposition data provided for each trial are drops per square centimeter, volume median diameter (VMD) and swath width. All data are from card deposits. The trials were purposely conducted over a range of weather conditions to represent actual aerial spray operations anticipated in Oregon.

In order to estimate the expected swath widths for each aircraft, AGDISP and FSCBG model runs were conducted prior to the field trials. The runs were conducted for a variety of aircraft and were meant to simulate the meteorological conditions, aircraft and spray characteristics of the Pacific Northwest Region (Region 6) 1988 western spruce budworm pre-project characterization trials. Results of the pretest predictions are reported by Skyler, Barry and Warner (1989) and by Teske (1988). Whenever possible, the data generated by these pretest predictions will be compared to both the field test data and the current FSCBG predictions.

2. Field Trials Summary

2.1 Spray Site

Figure 1 shows a diagram of the test site at Growers Air Service. The spray deposit sample line was set up in a plowed and furrowed field. There were fifty positions 3m apart along a 150m line positioned at 45 degrees southwest to northeast. Each position consisted of a Kromekote ground card and a 30.5cm high stake with a Kromekote strip secured over the top with surface areas on the north and south sides of the stake. Douglas-fir foliage was also secured to the top of stakes at selected positions on selected trials. Data collected from elevated samplers and from the foliage is not addressed in this paper. Steinke and Silva (1992) concluded that drop capture on the top (foliage) and sides (collector cards) of the stakes was not consistent with the ground deposition data.

2.2 Meteorology Measurements

Wind speed, wind direction, temperature and relative humidity were measured at the west end of the sampler line with instruments available in the FS fire belt weather kit. All data were taken at 2m above the ground. Table 1 summarizes the meteorological data for each trial. As previously noted, the trials were conducted over a wide range of weather conditions. Over the six days of testing, relative humidity during field tests ranged from a low of 20% to a high of 90% and temperature ranged from 2.8 to 25.6 degrees C. Table 1 also shows the average temperature, relative humidity and wind direction for the forty four trials. The relative standard deviation of these variables (defined as the ratio of standard deviation to the average) indicates a large degree of variability in the meteorological data.

The wind speed during the trials was generally low, only exceeding 5m/s during trials 2, 3, and 4. Wind direction was generally within 20 degrees of the aircraft heading, but was variable for trials 20, 21, 22, 27 and 42. Trials 20, 21, and 22 were flown with a 50 degree difference in the wind direction and aircraft heading, and trial 24 was flown with a 70 degree difference. Trials 23 and 25 were flown perpendicular to the wind, which was blowing directly over the sampler line.

Although the trials are numbered from 1 to 45, trial 41 was a no data trial and is not included in the data analysis.

2.3 Spray Aircraft Configuration

The spray trials were conducted with two aircraft, an Air Tractor AT-301 single engine airplane and a Bell 205 A-1 helicopter. Three types of rotary atomizers were used: Beecomist 360A, Micronair AU4000 and Micronair AU5000. These atomizers were positioned on a boom located under the wing of the airplane or at the bottom of the helicopter fuselage, perpendicular to the fuselage centerline.

All trials conducted with the Air Tractor used six Micronair AU4000 atomizers, three on either side of the fuselage. The atomizers were positioned along the boom as tabulated in Table 2. Trials 1-3, 5-7 and 11-14 were conducted with configuration A, and trials 15-16, 22-24 and 27-37 were conducted with configuration B.

Trials conducted with the helicopter used two types of atomizers in eight positions along the boom (Table 2). Trials 17-21, 25-26, and 38-40 were conducted with Beecomist atomizers in configuration C and trials 4 and 8-10 were conducted with Beecomist atomizers in configuration D. Trials 42-45 were conducted with Micronair AU5000 atomizers in configuration C.

Table 3 shows the spray system variables for each trial. Note that trials 11-16 and 34-37 were all conducted with the same Bt formulation in Micronair AU4000 atomizers on the Air Tractor, but the atomizers were configured differently for trials 11-14 than for trials 15-16 and 34-37.

2.4 Spray Characteristics

Aircraft altitude for the trials varied from 12.2 to 30.5m AGL and speed varied from 33.5 to 51.4 m/s. Table 4 summarizes the aircraft system variables for each trial. Aircraft speed shown is the radar measured air speed from the field test data.

For each trial, the aircraft flew over the sampler line into the wind and sprayed for approximately 1 km, either over the center of the line or offset to the east or west to compensate for variation in wind direction (Steinke and Silva 1992). The offset was intended to contain most of the spray deposits within the sampler line.

Dipel 6AF, Dipel 6L, Thuricide 48LV and Thuricide 32LV formulations of Bt were sprayed undiluted at the application rates shown in Table 3. Dipel 6AF, Dipel 6L and Thuricide 48LV were sprayed at 5.30 l/min in the Beecomist atomizer and at 7.19 l/min in the Micronair AU4000. Thuricide 32LV was sprayed at 7.91 l/min in the Beecomist atomizer and at 9.46 l/min in the Micronair AU4000. Dipel 6L was also sprayed at 4.26 l/min in the Micronair AU5000 atomizer (except for trial 42). Dipel 6L is an oil-based solution with a volatile fraction of zero. The other formulations are all aqueous. The drop size characteristics for each formulation are given in Table 5.

Spray deposit cards were assessed following the spray pass by four detailers from Eldorado NF and one from Nez Perce NF who used 7X powered hand-held occulars (Steinke and Silva 1992). Ground deposition data from each trial includes number of drops deposited per square centimeter and VMD and is presented and analyzed in Steinke and Silva (1992). This data is the basis for comparison with FSCBG predictions of deposition. No measurement of mass deposition was included in the field test data report.

2.5 Results

Steinke and Silva (1992) define the swath width for each trial using a criteria of 10 or more drops per square centimeter. They note that several of the trials conducted with the aqueous formulations showed very small amounts of deposition. Trials 9, 13, 14, 17, 18, 19, 26, 33, and 36 do not indicate any swath width and so are not further analyzed.

Swath width and mean ground deposition were found to be virtually independent of wind speed (Steinke and Silva 1992). However, in conditions of very low wind speed and variable wind direction the ground deposition patterns were determined to be inconsistent and with no particular pattern. The best uniformity of droplet distribution was found for those trials which were truly conducted into the wind. The oil-based formulation Dipel 6L generally showed the largest swath widths.

Despite the attempt to fully contain the swath deposit for each trial, ground cards on the ends of the sample lines showed deposits in 77% of the trials. Steinke and Silva (1992) note that most of these occurrences were beyond their measured swath width (ie, less than 10 drops per square centimeter). Nevertheless, the edge of deposition in many of the trials was not clearly defined.

When grouped by formulation and type of aircraft, Steinke and Silva (1992) found no obvious correlation between relative humidity and mean deposition for any of the sets of trials. There was also no apparent relation of release height and crosswind to the offset of deposit from the center of the flight path. No comparisons with the pretest predictions were made by Steinke and Silva (1992).

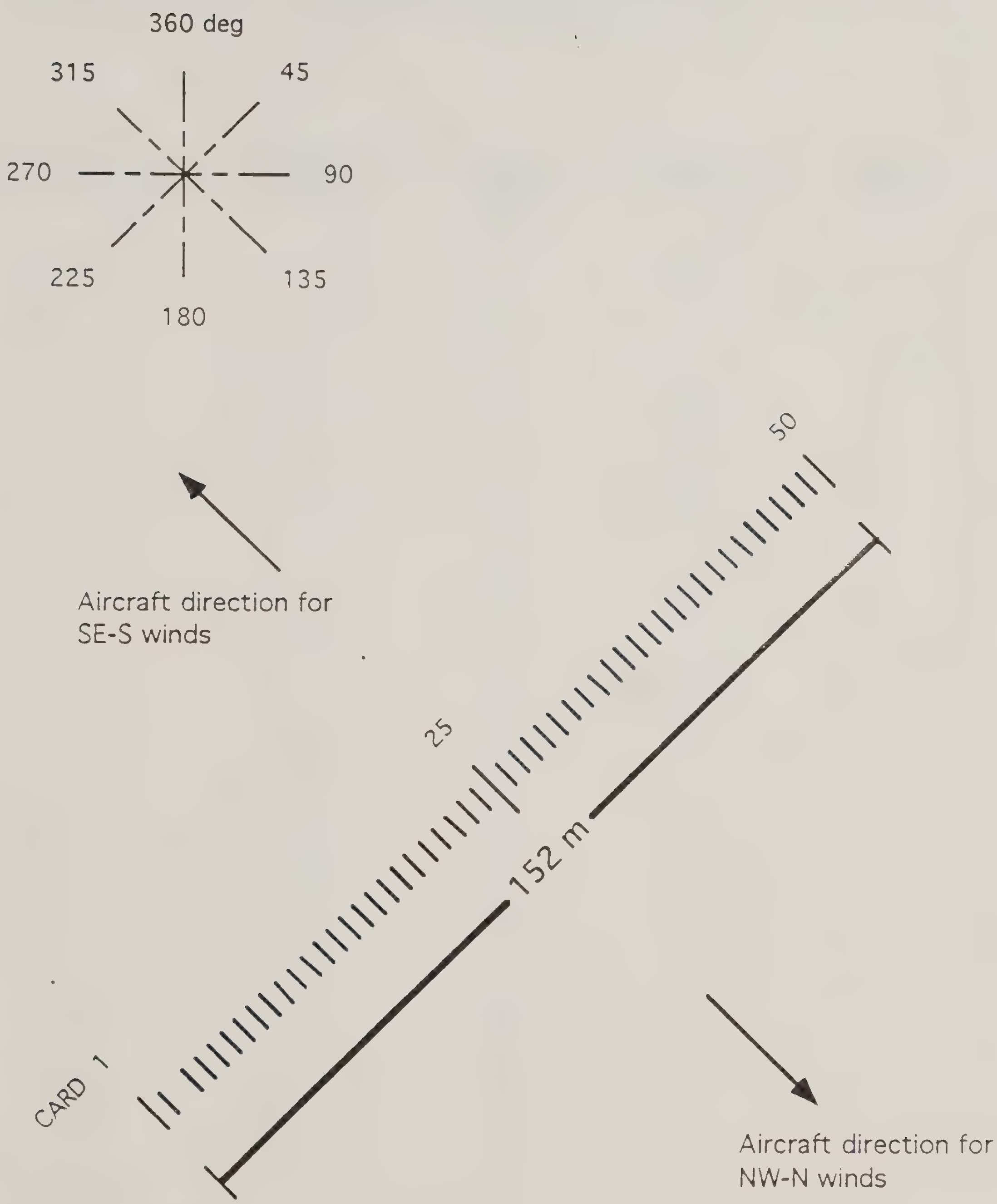


FIGURE 1: Test site at Growers Air Service.

TABLE 1: Summary of meteorology data for the Davis spray trials.
** denotes variable wind direction

Trial #	Temperature (deg C)	Relative Humidity (%)	Wind Speed (m/s)	Wind Direction (deg. from North)
1	25.6	78	4.9	300
2	7.8	76	7.2	320
3	11.1	67	8.0 (gusts)	320
4	18.3	27	5.4	320
5	16.7	20	3.6	320
6	12.8	34	3.6	280
7	13.3	46	2.7	310
8	4.4	44	0.9	320
9	2.8	90	1.3	280
10	5.6	53	0.9	310
11	7.8	52	1.8	280
12	12.8	33	3.1	310
13	12.2	38	4.5	320
14	12.8	38	2.7	340
15	18.3	39	0.9	280
16	17.8	36	0.9	280
17	17.8	36	0.4	300
18	17.2	33	0.4	300
19	2.8	82	0.9	308
20	3.9	58	0.4	0**
21	8.9	52	0.4	0**
22	5.6	68	0.4	0**
23	8.3	66	0.9	225
24	9.4	61	1.3	65

TABLE 1 (Cont'd.): Summary of meteorology data for the Davis spray trials.
** denotes variable wind direction

Trial #	Temperature (deg C)	Relative Humidity (%)	Wind Speed (m/s)	Wind Direction (deg. from North)
25	11.7	74	1.8	50
26	12.8	72	1.8	135
27	13.3	65	1.3	135**
28	18.9	48	2.2	140
29	18.3	48	1.8	130
30	17.2	51	2.2	140
31	5.0	84	1.8	320
32	3.3	85	2.7	330
33	6.7	82	2.7	320
34	10.0	74	2.7	320
35	11.1	63	1.8	320
36	12.8	65	2.2	320
37	13.9	62	2.2	310
38	21.1	37	0.9	120
39	20.0	42	0.9	120
40	18.3	48	0.4	120
42	8.3	79	0.4	315**
43	8.3	79	0.9	310
44	11.7	75	2.7	320
45	12.8	70	2.7	320
Average:	12.0	58	2.1	
Relative standard deviation:	0.46	0.32	0.80	

TABLE 2: Atomizer positions along the spray boom. Location is defined as positive to the pilot's right, with 0.0 at the aircraft centerline.

Configuration	Atomizer location (m)
A	4.75
	3.31
	1.66
	-1.37
	-3.06
	-4.41
B	3.38
	2.56
	1.70
	-1.42
	-2.24
	-3.10
C	4.43
	3.85
	3.06
	2.31
	-2.37
	-3.38
	-4.20
	-4.81
D	5.80
	4.80
	3.59
	2.36
	-2.34
	-3.42
	-4.47
	-5.85

TABLE 3: Spray system variables for the Davis spray trials. Rotary atomizers referred to are the Beecomist 360A and the Micronair AU4000. Micronair** is the Micronair AU5000 rotary atomizer. Atomizer configurations are shown in Table 2.

Trial #	Formulation	Aircraft	Atomizer	Atomizer position	Flow Rate (l/min)
1	Dipel 6L	AT-301	Micronair	A	7.19
2	Dipel 6L	AT-301	Micronair	A	7.19
3	Dipel 6L	AT-301	Micronair	A	7.19
4	Dipel 6AF	Bell 205 A-1	Beecomist	D	5.30
5	Dipel 6L	AT-301	Micronair	A	7.19
6	Dipel 6L	AT-301	Micronair	A	7.19
7	Dipel 6L	AT-301	Micronair	A	7.19
8	Dipel 6AF	Bell 205 A-1	Beecomist	D	5.30
9	Dipel 6AF	Bell 205 A-1	Beecomist	D	5.30
10	Dipel 6AF	Bell 205 A-1	Beecomist	D	5.30
11	Dipel 6AF	AT-301	Micronair	A	7.19
12	Dipel 6AF	AT-301	Micronair	A	7.19
13	Dipel 6AF	AT-301	Micronair	A	7.19
14	Dipel 6AF	AT-301	Micronair	A	7.19
15	Dipel 6AF	AT-301	Micronair	B	7.19
16	Dipel 6AF	AT-301	Micronair	B	7.19
17	Thuricide 48LV	Bell 205 A-1	Beecomist	C	5.30
18	Thuricide 48LV	Bell 205 A-1	Beecomist	C	5.30
19	Thuricide 48LV	Bell 205 A-1	Beecomist	C	5.30
20	Thuricide 48LV	Bell 205 A-1	Beecomist	C	5.30
21	Thuricide 48LV	Bell 205 A-1	Beecomist	C	5.30
22	Thuricide 48LV	AT-301	Micronair	B	7.19
23	Thuricide 48LV	AT-301	Micronair	B	71.9
24	Thuricide 48LV	AT-301	Micronair	B	7.19

TABLE 3 (Cont'd.): Spray system variables for the Davis spray trials. Rotary atomizers referred to are the Beecomist 360A and the Micronair AU4000. Micronair** is the Micronair AU5000 rotary atomizer. Atomizer configurations are shown in Table 2.

Trial #	Formulation	Aircraft	Atomizer	Atomizer position	Flow Rate (l/min)
25	Thuricide 32LV	Bell 205 A-1	Beecomist	C	7.91
26	Thuricide 32LV	Bell 205 A-1	Beecomist	C	7.91
27	Thuricide 32LV	AT-301	Micronair	B	9.46
28	Thuricide 32LV	AT-301	Micronair	B	9.47
29	Thuricide 32LV	AT-301	Micronair	B	9.46
30	Thuricide 32LV	AT-301	Micronair	B	9.46
31	Thuricide 32LV	AT-301	Micronair	B	9.46
32	Thuricide 32LV	AT-301	Micronair	B	9.46
33	Thuricide 32LV	AT-301	Micronair	B	9.46
34	Dipel 6AF	AT-301	Micronair	B	7.19
35	Dipel 6AF	AT-301	Micronair	B	7.19
36	Dipel 6AF	AT-301	Micronair	B	7.19
37	Dipel 6AF	AT-301	Micronair	B	7.19
38	Dipel 6L	Bell 205 A-1	Beecomist	C	5.30
39	Dipel 6L	Bell 205 A-1	Beecomist	C	5.30
40	Dipel 6L	Bell 205 A-1	Beecomist	C	5.30
42	Dipel 6L	Bell 205 A-1	Micronair**	C	2.88
43	Dipel 6L	Bell 205 A-1	Micronair**	C	4.26
44	Dipel 6L	Bell 205 A-1	Micronair**	C	4.26
45	Dipel 6L	Bell 205 A-1	Micronair**	C	4.26

TABLE 4: Aircraft variables for the Davis spray trials.

Trial #	Aircraft Height (m)	Aircraft Speed (m/s)	Trial #	Aircraft Height (m)	Aircraft Speed (m/s)
1	15.24	43.81	25	15.24	40.69
2	12.19	51.40	26	15.24	37.55
3	12.19	51.40	27	15.24	49.17
4	19.81	33.52	28	13.72	45.59
5	15.24	40.68	29	15.24	46.94
6	15.24	47.83	30	15.24	48.72
7	16.76	47.83	31	15.24	46.94
8	19.81	34.87	32	15.24	47.38
9	15.24	36.21	33	15.24	46.04
10	15.24	39.34	34	15.24	47.83
11	15.24	49.17	35	30.48	43.81
12	12.19	51.40	36	22.86	46.94
13	30.48	42.91	37	15.24	48.28
14	30.48	51.40	38	15.24	37.10
15	15.24	46.94	39	15.24	42.46
16	15.24	48.72	40	15.24	42.02
17	13.72	38.44	42	15.24	37.10
18	15.24	42.02	43	15.24	38.89
19	15.24	40.23	44	13.72	38.44
20	15.24	38.00	45	15.24	38.00
21	15.24	39.34			
22	15.24	44.70			
23	15.24	47.83			
24	15.24	47.83			

TABLE 5: Drop size characteristics for Bt formulations: Thuricide 32LV and Thuricide 48LV in the Beecomist 360A and Micronair AU4000 rotary atomizers (John W. Barry, USDA Forest Service, private communication, and Skyler and Barry 1991). Note that these are aqueous solutions .

Thuricide 48LV, Beecomist 360A

Specific Gravity = 1.145
Volatile Fraction = 0.50

Average Diameter (micrometers)	Mass Fraction
45.88	0.2609
73.78	0.2430
106.35	0.2005
138.62	0.1791
171.03	0.0874
203.42	0.0265
235.88	0.0022
268.32	0.0004

Thuricide 32LV, Beecomist 360A

Specific Gravity = 1.145
Volatile Fraction = 0.50

Average Diameter (micrometers)	Mass Fraction
45.88	0.0705
73.78	0.0394
106.35	0.1616
138.62	0.2456
171.03	0.2135
203.42	0.1361
235.88	0.0752
268.32	0.0401
301.32	0.0140
334.77	0.0034
366.72	0.0005
398.21	0.0001

Thuricide 48LV, Micronair AU4000

Specific Gravity = 1.145
Volatile Fraction = 0.50

Average Diameter (micrometers)	Mass Fraction
45.88	0.1516
73.78	0.2415
106.35	0.3573
138.62	0.1970
171.03	0.0426
203.42	0.0060
235.88	0.0023
268.32	0.0007
301.32	0.0002
334.77	0.0000
366.72	0.0008

Thuricide 32LV, Micronair AU4000

Specific Gravity = 1.145
Volatile Fraction = 0.50

Average Diameter (micrometers)	Mass Fraction
45.88	0.0847
73.78	0.2375
106.35	0.3334
138.62	0.2421
171.03	0.0825
203.42	0.0148
235.88	0.0046
268.32	0.0003
301.32	0.0001

TABLE 5 (Cont'd.): Drop size characteristics for Bt formulations: Dipel 6AF and Dipel 6L (John W. Barry, USDA Forest Service, private communication, and Skyler and Barry 1991). For these Dipel solutions, the same drop size characteristics were used for the Beecomist 360A, Micronair AU4000 and Micronair AU5000 rotary atomizers. Note that Dipel 6AF is an aqueous solution and Dipel 6L is an oil-based solution.

Dipel 6AF

Specific Gravity = 1.145
Volatile Fraction = 0.50

Average Diameter (micrometers)	Mass Fraction
45.88	0.1807
73.78	0.3105
106.35	0.2724
138.62	0.1486
171.03	0.0614
203.42	0.0167
235.88	0.0060
268.32	0.0021
301.32	0.0013
334.77	0.0003

Dipel 6L

Specific Gravity = 0.90
Volatile Fraction = 0.10

Average Diameter (micrometers)	Mass Fraction
45.88	0.1159
73.78	0.1807
106.35	0.2008
138.62	0.2653
171.03	0.1542
203.42	0.0682
235.88	0.0137
268.32	0.0010
301.32	0.0002

3. FSCBG Simulation of Field Test Data

The objective of this paper is to compare FSCBG predictions of deposition with the field test results. A detailed description of input parameters necessary for FSCBG modeling may be found in Teske and Curbishley (1991).

Spray application rate, aircraft altitude and aircraft weight, relative humidity and temperature vary for each trial according to the field test data as previously shown in Tables 1, 3 and 4.

Aircraft configuration and powerplant data required by FSCBG are summarized in Table 6. FSCBG version 4.1 includes AT-301 and Bell 205 A-1 modules in its library of standard aircraft configurations. Configuration of rotary atomizers along the boom is as illustrated in Table 2.

Drop size characteristics used to generate FSCBG predictions of deposition for each Bt formulation are as shown in Table 5. There were nine combinations of formulation and atomizer tested during the Davis trials. Four Bt formulations (Dipel 6L, Dipel 6AF, Thuricide 32LV and Thuricide 48LV) were each tested using a Beecomist 360A atomizer and a Micronair AU4000 atomizer. In addition, Dipel 6L was tested using a Micronair AU5000 atomizer. All of the formulations tested were undiluted (neat). The FSCBG version 4.1 standard drop size library includes only one of the nine combinations at the correct dilution (Thuricide 48LV sprayed undiluted in a Beecomist atomizer). There is no drop size data available for a Micronair AU4000 atomizer, only for a Micronair AU5000. Drop size spectra for Thuricide 32LV and Dipel 6L are only available at dilutions of 1:1 or greater. There is no data in the library for Dipel 6AF.

The following drop size characteristics from the FSCBG library were used to model Bt formulations used in the trials, as displayed in Table 5: Thuricide 48LV undiluted in a Beecomist atomizer; Thuricide 48LV undiluted in a Micronair AU5000 atomizer; Thuricide 32LV 1:1 in a Beecomist atomizer; Thuricide 32LV 1:1 in a Micronair AU5000 atomizer; Foray 48B undiluted in a Micronair AU5000 atomizer (for Dipel 6AF in both atomizers); and Dipel 8L undiluted in a Beecomist atomizer (for Dipel 6L in both atomizers). Preliminary simulations of test data indicated that some adjustment to drop size was necessary for trials conducted in conditions of very little wind, low temperature and high relative humidity.

TABLE 6: Aircraft characteristics for the Air Tractor AT-301 and the Bell 205 A-1.

Aircraft	Air Tractor AT-301
Type	Fixed-wing
Weight	2541.28 kg
Wing span	13.78 m
Planform area	23.33 m sq
Drag coefficient	0.10
Propeller radius	1.37 m
Propeller efficiency	0.80
Blade RPM	2250.00

Aircraft	Bell 205 A-1
Type	Helicopter
Weight	3492.90 kg
Rotor diameter	13.78 m
Blade RPM	309.00

4. Results and Discussion

Comparison plots of field test deposition data and FSCBG deposition predictions for each of the forty four spray trials are presented in the Appendix. Deposition variables examined are drops per square centimeter over the optimum card line. FSCBG simulations are plotted as solid lines and field test data are plotted as open circles. Each of the comparison plots is briefly evaluated below. FSCBG predictions were adjusted to account for two factors: orientation of the field test deposition data and position of the aircraft over the test circle.

FSCBG generates deposition data along a line perpendicular to the aircraft flight path; this line is not always oriented along the field test sampler line. For example, the wind direction in trial 6 was 280 degrees. Since the aircraft flew into the wind, the sampler line (positioned at 45-225 degrees, as shown in Figure 1 was 35 degrees from the FSCBG prediction line. When necessary, FSCBG predictions are adjusted to the orientation of the sampler card line.

In order to keep the entire width of the swath over the sampler line, the aircraft flight path was usually offset from center during testing (Steinke and Silva 1992); FSCBG simulations are adjusted accordingly.

Qualitatively, the FSCBG model predictions do a very good job of simulating ground deposition for most of the Davis trials. The quantitative measure of correlation coefficient reduces the comparison to a single number, which may not entirely reflect the quality of the prediction.

Table 7 contains the correlation coefficients comparing the field test data (drops per square centimeter) with FSCBG predictions. This table gives a quick summary of the test results and corresponding FSCBG predictions. As previously noted, Steinke and Silva (1992) did not analyze those trials which resulted in no measurable swath; thus, correlation coefficients for trials 9, 13, 14, 17, 18, 19, 26, 33, and 36 are not included in the calculation. The average correlation for the remaining trials is $R^2 = 0.65$, with values ranging from $R^2=0.31$ to $R^2=0.89$. Trials conducted with Thuricide 48LV show the best correlation, with an average of $R^2=0.76$. For the Thuricide 48LV trials, the average correlation for those done with Beecomist atomizers was $R^2=0.82$ while the average for those done with Micronair atomizers was $R^2=0.70$. Average correlation for the remaining trials, by formulation, is: $R^2=0.67$ for Thuricide 32LV; $R^2=0.64$ for Dipel 6AF; and $R^2=0.57$ for Dipel 6L.

Thus, the best model correlation occurs when the correct drop size distribution data is used. Thuricide 48LV with the Beecomist atomizer was the only distribution used directly from the database; all other distributions had to be assumed or approximated, and the model comparisons with field data suffered accordingly.

Field test data and FSCBG simulations are also compared by means of Table 8, which shows the swath width calculated for each trial, and Figure 2, a scatterplot of the field test and predicted swath widths. As previously stated, Steinke and Silva (1992) defined swath width as that portion of the ground deposition which was 10 or more drops per square centimeter. Data from all of the trials is shown, including those where measured ground deposition was less than 10 drops per square centimeter across the entire card line.

In general, FSCBG appears to predict swath width very well. Correlation for all forty four trials shows a least squares slope through the data comparison of 0.66 (Figure 2) and an R^2=0.66. These values are especially promising since field data was only available in 3m increments while the FSCBG predictions are generated in increments of less than 0.5m. By formulation, the correlation coefficients (swath width) for trials run with Dipel 6AF, Thuricide 32LV and Thuricide 48LV are all very good (R^2=0.76, 0.60, and 0.57, respectively), but the correlation coefficients for trials run with Dipel 6L are very low (R^2=0.13). These results are in keeping with the predictions for ground deposition shown in the Appendix: FSCBG predictions of drops deposited for trials using Dipel 6AF, Thuricide 32LV and Thuricide 48LV were generally more accurate than predictions for trials using Dipel 6L.

In some of the trials where FSCBG predictions correlated well with field test data the deposition profile predicted was not consistent with measured deposition below the 10 drops per square centimeter threshold for swath width calculation. Thus it is possible to see a high correlation coefficient (R^2 for drops) and accurate prediction of swath width despite a discrepancy in deposition profile, as long as the profile above 10 drops per square centimeter is predicted well.

Note that for five of the nine trials with peak deposition below 10 drops per square centimeter, the predicted deposition was also below this threshold. Trial 36 had peak deposition below 10 drops per square centimeter in the field test and the prediction was above the drop threshold. This is a small difference and is probably due to incorrect drop size characteristics (trial 36 was conducted with Dipel 6AF). Predicted peak deposits for trials 19, 26 and 33 are all greater than 10 drops per square centimeter. Each of these three trials was conducted in meteorological conditions similar to other trials with the same formulation, aircraft and spray variables which resulted in peak deposition greater than 10 drops per square centimeter. For example, trials 32 and 33 (Thuricide 32LV in Micronair atomizers on an Air Tractor) were performed under nearly identical meteorological conditions, yet the field test data shows entirely different ground deposition patterns for these two trials. The same is true for trials 25 and 26 (Thuricide 32LV in Beecomist atomizers on a Bell 205 A-1) and for trials 19 and 20 (Thuricide 48LV in Beecomist atomizers on a Bell 205 A-1).

Table 9 shows the volume median diameter (VMD) of droplets for each trial as calculated by FSCBG. The average for all runs is 63.0 micrometers. VMD measurements as tabulated by Steinke and Silva (1992) are not included here because they are erratic and because there was no measurement of mass deposited during the field test.

Table 10 shows a comparison of FSCBG pretest predictions to field test data and to current predictions. Pretest predictions are available for the Bell 205 A-1 and the AT-301 spraying Dipel 6L and Thuricide 32LV in Beecomist atomizers (Skyler, Barry and Warner 1989 and Teske 1988). As previously discussed, the pretest predictions reported by Skyler, Barry and Warner (1989) were modeled with meteorological conditions and aircraft and spray variables taken from the Region 6, 1988 western spruce budworm characterization trials. Predictions reported by Teske (1988) were performed just prior to the Davis spray trials and were meant to encompass the aircraft configuration and test conditions there. However, actual field test meteorological conditions, spray variables, and even aircraft variables were considerably different from those used to model the pretest predictions in both of these reports.

From the two reports of pretest predictions, comparisons can be made to trials 1, 5, 6, 7, 26, 27, 31, 32, 33, 39, and 40. Each of these trials is reasonably well represented by an FSCBG pretest prediction model, although none of the trials was conducted in meteorological conditions exactly like those used in the pretest predictions. In fact, pretest predictions for trials 39 and 40 were modeled with substantially different temperature and relative humidity conditions than the actual field test data.

In light of the difficulties previously discussed regarding the modeling of drop size characteristics for Bt formulations used in the Davis trials, it is apparent that drop size characteristics used in the current FSCBG predictions are different from those used in the pretest predictions. Table 10 indicates that the average swath widths, measured and predicted, are lower than the pretest predictions. Even with the drop size discrepancy, it is suspected that meteorological variables are also responsible for this difference. Previous work (Teske and Barry 1993) suggest the importance of accurate estimates of temperature and relative humidity. Perhaps, future pretest predictions should cover a broad range of ambient field conditions when computing swath width. Both meteorological and drop size characteristics have played significant roles in the difference between pretest and actual swath widths, as summarized in Table 10.

TABLE 7: Correlation coefficients for trials 1-45 comparing field data and FSCBG predictions for drops deposited. Trials with correlation coefficients above 0.50 are considered "good."

Trial #	Correlation to Drops	Comments
1	0.87	Good comparison.
2	0.75	Good comparison.
3	0.48	Peak value under predicted; predicted swath width is close.
4	0.79	Good comparison.
5	0.60	Peak value and swath width under predicted.
6	0.55	Good comparison.
7	0.73	Good comparison.
8	0.86	Good comparison.
9	---	Peak value over predicted.
10	0.45	Fair comparison.
11	0.37	Predicted deposition profile and swath width are close.
12	0.60	Predicted deposition profile and swath width are narrow.
13	---	Good comparison.
14	---	Good comparison.
15	0.37	Predicted deposition profile close.
16	0.74	Good comparison.
17	---	Deposition profile under predicted.
18	---	Deposition profile under predicted.
19	---	Deposition over predicted and gives non-zero swath width.
20	0.85	Good comparison; note that swath is only partially captured.
21	0.78	Deposition profile and swath width correct; peak value over predicted.
22	0.78	Deposition profile under predicted.
23	0.67	Deposition profile correct but slightly over predicted; see note A.
24	0.65	Good comparison.

TABLE 7 (Cont'd.): Correlation coefficients for trials 1-45 comparing field data and FSCBG predictions for drops deposited. Trials with correlation coefficients above 0.50 are considered "good."

Trial #	Correlation to Drops	Comments
25	0.60	Deposition profile under predicted; see note A
26	---	Deposition profile over predicted.
27	0.73	Good comparison; swath width wide.
28	0.84	Good comparison.
29	0.50	Peak deposition under predicted.
30	0.89	Good comparison.
31	0.83	Good comparison.
32	0.62	Deposition profile under predicted.
33	---	Deposition profile over predicted.
34	0.45	Predicted swath width too narrow.
35	0.70	Good comparison.
36	---	Peak deposition under predicted.
37	0.88	Good comparison.
38	0.32	Swath width too narrow.
39	0.72	Predicted deposition correct inside the swath.
40	0.51	Good comparison.
42	0.59	Deposition profile under predicted.
43	0.31	Deposition profile under predicted.
44	0.84	Deposition profile under predicted.
45	0.39	Swath width too narrow.
Average	0.65	

Note A: In trials 23 and 25 the aircraft flew directly along the card line. Thus, the model predictions could only recover a single value of deposition between the assumed flow-on and flow-off points along the spray path.

TABLE 8: Swath width calculations for the Davis trials. Swath width is defined as ≥ 10 drops per square centimeter.

Trial #	Field test swath width (m)	Predicted swath width (m)	Trial #	Field test swath width (m)	Predicted swath width (m)
1	40	42	25	Note A	80
2	18	36	26	0	25
3	46	35	27	6	22
4	12	16	28	46	34
5	76	44	29	58	42
6	46	42	30	36	31
7	46	38	31	40	47
8	12	20	32	73	40
9	0	0	33	0	45
10	18	40	34	91	40
11	15	20	35	9	5
12	15	25	36	0	10
13	0	0	37	55	54
14	0	0	38	100	40
15	12	22	39	46	48
16	12	18	40	64	38
17	0	0	42	64	38
18	0	0	43	79	39
19	0	45	44	43	40
20	24	26	45	43	40
21	36	35			
22	82	32			
23	Note A	65			
24	9	17			

Correlation coefficient for trials 1-45: R^2=0.66

Note A: In trials 23 and 25 the aircraft flew directly over the card line. Thus, swath width is unrecoverable from field data.

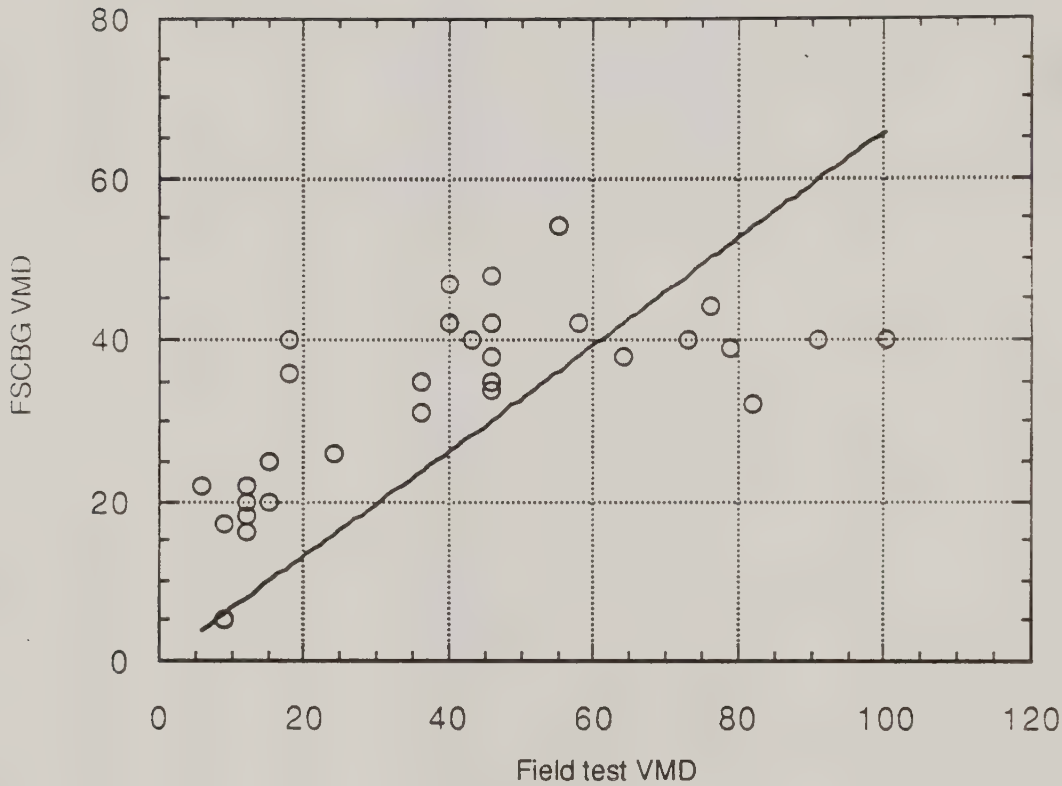


FIGURE 2: Predicted and field test values of swath width (swath width is defined for ground deposition ≥ 10 drops per square centimeter).
Least squares slope =0.66 with R^2=0.66.

TABLE 9: Volume Median Diameter (VMD) for the Davis trials as predicted by FSCBG.

Trial #	Predicted VMD (micrometers)	Trial #	Predicted VMD (micrometers)
1	64	25	69
2	64	26	71
3	64	27	68
4	66	28	69
5	68	29	52
6	63	30	69
7	64	31	50
8	67	32	53
9	78	33	50
10	52	34	49
11	49	35	63
12	69	36	63
13	92	37	48
14	64	38	67
15	65	39	71
16	65	40	70
17	94	42	69
18	94	43	68
19	57	44	69
20	52	45	68
21	50		
22	46		
23	45	Average	63
24	45		

TABLE 10: Comparison of pretest FSCBG predictions, field test data and current FSCBG predictions of swath width for selected trials.

Trial #	Aircraft	Formulation	Pretest swath width (m)	Field test swath width (m)	Predicted swath width (m)
1	AT-301	Dipel 6L	60	40	42
5	AT-301	Dipel 6L	60	76	44
6	AT-301	Dipel 6L	60	46	42
7	AT-301	Dipel 6L	60	46	38
26	Bell 205 A-1	Thuricide 32LV	90	---	25
27	AT-301	Thuricide 32LV	80	6	19
31	AT-301	Thuricide 32LV	80	40	30
32	AT-301	Thuricide 32LV	80	73	40
33	AT-301	Thuricide 32LV	80	---	45
39	Bell 205 A-1	Dipel 6L	60	46	48
40	Bell 205 A-1	Dipel 6L	60	64	38
		Average	72	40	37

5. Conclusions

FSCBG predictions of the Davis trials ground deposition data show very good correlation, with an overall R^2=0.65. Predictions of swath width were also quite good, with an overall correlation of R^2= 0.66. These values are well within the acceptable level for operational field tests. However, predicted deposition would probably have been even better if the proper drop size characteristics had been available for FSCBG modeling.

Drop size characteristics were available for only one of the nine combinations of undiluted Bt formulation and atomizer type used in the Davis trials (Thuricide 48LV in a Beecomist atomizer). Drop size characteristics used for the other eight combinations were not truly representative of the actual formulations being sprayed. Thus, the correlation of predicted deposition to field test data is much better for the one formulation modeled with correct drop size data than it is for any of the other formulations. Average correlation (drops) for Thuricide 48LV in Beecomist atomizers is R^2=0.82; for Thuricide 48LV in Micronair AU4000 atomizers (drop size data used is for a different type of Micronair atomizer) R^2=0.70. Average correlation for Thuricide 32LV, Dipel 6AF and Dipel 6L is less than 0.70.

Although the overall correlation of predicted data to field test data is good, the deposition profiles predicted in some of the trials are incorrect, and there are several trials for which deposition is under predicted. A measurement of mass deposited in each trial during field testing is essential to model validation. Had this type of data been available, a more thorough evaluation of FSCBG predictive capability could have been accomplished.

A wind tunnel test of Bt formulations and nozzle types that are currently in use by the USDA Forest Service is suggested in order to expand the existing database of drop size characteristics available to FSCBG users. Furthermore, the existing database should be extended to drops below 34 micrometers by more detailed wind tunnel tests to 10 microns. Extrapolation of existing data may generate distributions that will not accurately represent the smallest drop sizes.

6. Field Test Recommendations

Overall, FSCBG performed quite well against the 1988 Davis Spray Characterization Trials, even with the limitations discussed in previous sections:

1. Only the most basic meteorological measurements were made

2. Drop size distributions and volatility were assumed

3. Mass was not recovered on the witness cards

Any one of these three restrictions could have severely impacted model comparison with field data. The fact that most of the trials compared well (with correlation coefficients above 0.50 as shown in Table 7) suggests that FSCBG may be exercised when only approximate information is available, with some confidence in its predictions. In the best of all worlds (with no regard for the cost involved), FSCBG comparisons would be greatly enhanced with the following test plan additions:

1. Meteorological data should include instruments measuring temperature and relative humidity accurately from the time the aircraft flies over the card line(s) until the cards are collected.

2. Meteorological data should also include three accurate measurements of wind speed and direction (at three heights, up to the spray release height if possible), to extract the boundary layer profile and provide an accurate reading of the wind direction.

3. Simple site geometry, so that interpretation of field data does not require extensive and time-consuming analysis (MacNichol and Teske 1993).

4. Two or more card lines to check deposition variability along the flight path and help interpret turbulent eddy effects during spraying.

5. An accurate measure of spray release height, one of the most critical field parameters (Teske and Barry 1993).

6. Wind tunnel atomization of the spray material.

7. Volatility determination of the spray material.

8. Timely interpretation of the witness cards, to avoid contamination and degradation over time, and recovery of both drops and mass.

In addition, if swath width is needed to characterize the spray aircraft, the aircraft should be flown over a card line in a crosswind situation (R. Mickle, private communication, and Teske, Twardus and Ekblad, 1990).

7. Acknowledgment

These trials were made possible through the cooperation of Growers Air Service, Evergreen Helicopters, Eldorado National Forest, Missoula Technology and Development Center, and Forest Pest Management staffs of the Pacific Southwest Region and the Pacific Northwest Region. We especially recognize the support provided by Russ Stocker, Tim McConnell, Pat Skyler, Jim Hadfield, Gary Melchior, Bill Steinke, Dave Thomas, and Don Lasilla.

8. References

Anderson, D.E., D.R. Miller, Y. Wang, W.G. Yendol, K. Mierzejewski and M.L. McManus. 1992. Deposition of aerially applied Bt in an oak forest and its prediction with the FSCBG model. *Journal of Applied Meteorology* 31:1457-1466.

Barry, J.W., P.J. Skyler, M.E. Teske, J.E. Rafferty and B.S. Grim. 1993. Predicting and measuring drift of *Bacillus thuringiensis* sprays. *Environmental Toxicology and Chemistry* (to appear).

Bilanin, A.J., M.E. Teske, J.W. Barry and R.B. Ekblad. 1989. AGDISP: The aircraft spray dispersion model, code development and experimental validation. *Transactions of the ASAE* 32:327-334.

Boyle, D.G., J.W. Barry, C.O. Eckard, W.T. Taylor, W.C. McIntyre, R.K. Dumbauld and H.E. Cramer. 1975. DC-7B aircraft spray system for large-area insect control. Rep. No. DPG-DR-C980A. United States Army Dugway Proving Grounds. Dugway, UT.

MacNichol, A.Z. and M.E. Teske. 1993. FSCBG Model Comparisons with the C-130 spray trials. Report No. FPM 93-10. USDA Forest Service. Davis, CA.

Rafferty, J.E., R.K. Dumbauld, H.W. Flake, J.W. Barry and J. Wong. 1982. Comparison of modeled and measured deposition for the Withlacoochee spray trials. Report No. 83-1. USDA Forest Service. Davis, CA.

Rafferty, J. E. and B. S. Grim. 1992. A canopy penetration experiment in Gambel oak. SETAC 13th Annual Meeting. Cincinnati, OH.

Skyler, P.J. and J.W. Barry. 1991. Compendium of drop size spectra compiled from wind tunnel tests. Report No. FPM 90-9. USDA Forest Service. Davis, CA.

Skyler, P.J., J.W. Barry and J. Warner. 1989. FSCBG computer model predictions of swath widths - 1988 western spruce budworm project Pacific Northwest region. Report No. FPM 89-4. USDA Forest Service. Davis, CA.

Steinke, W.E. and H.R. Silva. 1992. Analysis of the USDA Forest Service 1988 aircraft spray characterization trials. Draft, March 1992. University of California. Davis, CA.

Teske, M.E. AGDISP code predictions for Davis airport trials. 1988. C.D.I. Technical Note No. 88-05. Continuum Dynamics, Inc. Princeton, NJ.

Teske, M.E. and J.W. Barry. 1993. Parametric sensitivity in aerial application. *Transactions of the ASAE* Vol. 36 No. 1, pp. 27-33.

Teske, M.E., K.P. Bentson, R.E. Sandquist, J.W. Barry and R.B. Ekblad. 1991. Comparison of FSCBG model predictions with Heather Seed Orchard deposition data. *Journal of Applied Meteorology* 30:1366-1375.

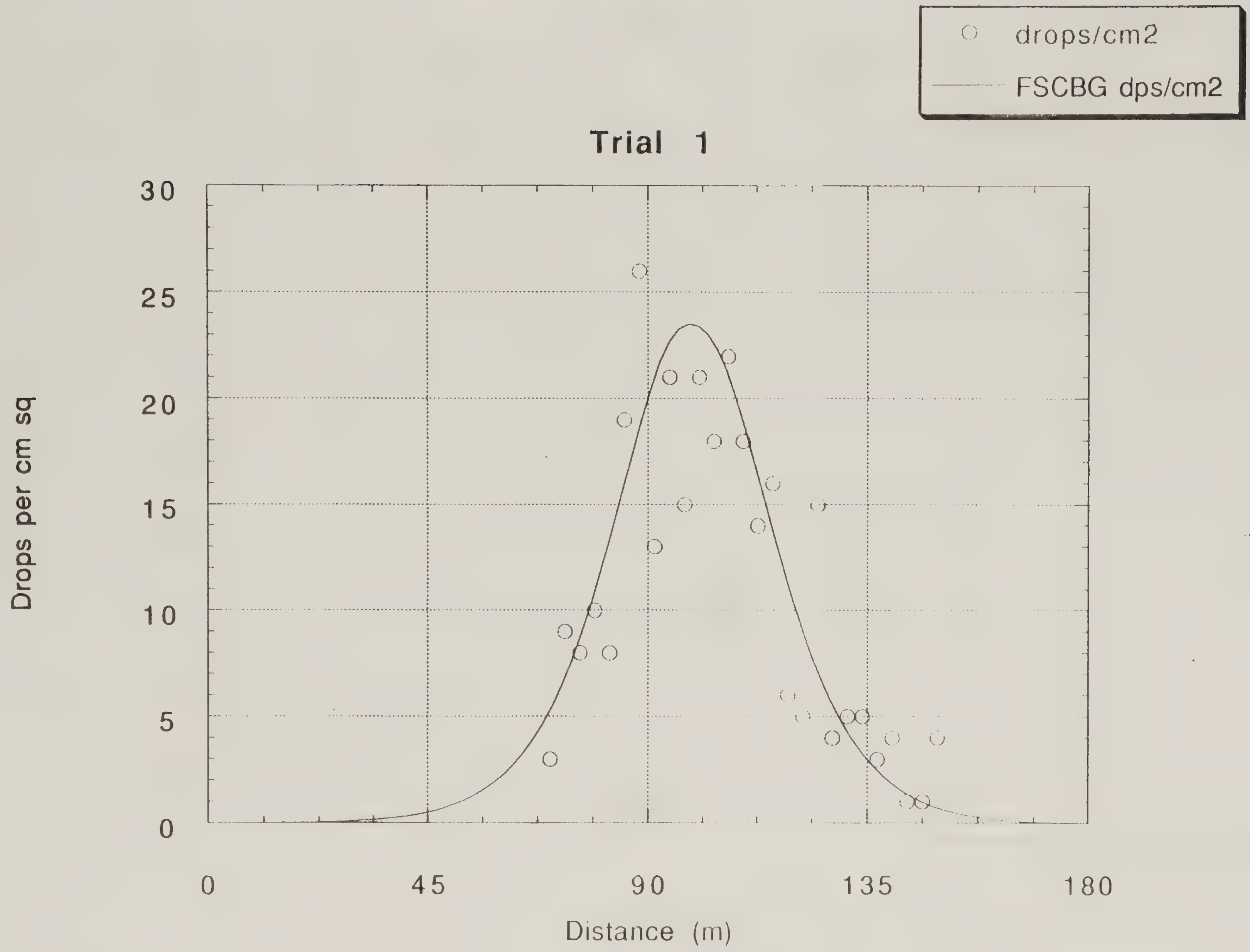
Teske, M.E., J.F. Bowers, J.E. Rafferty and J.W. Barry. 1993. FSCBG: an aerial spray dispersion model for predicting the fate of released material behind aircraft. *Environmental Toxicology and Chemistry* 12:453-464.

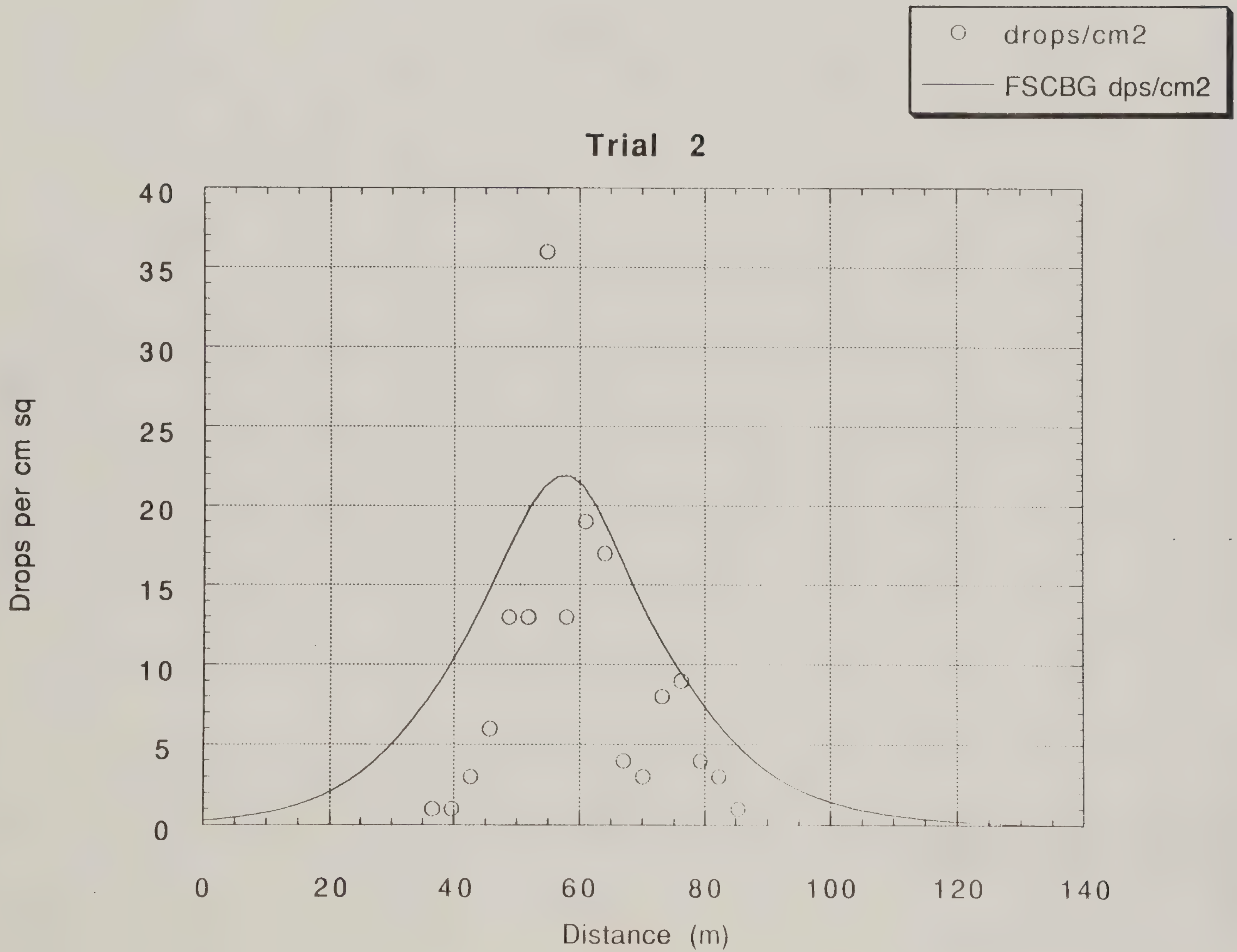
Teske, M.E. and T.B. Curbishley. 1991. Forest Service aerial spray computer model FSCBG version 4.0 user manual. Report No. FPM 91-1. USDA Forest Service. Davis, CA.

Teske, M. E., D. B. Twardus and R. B. Ekblad. 1990. Swath width evaluation. USDA Forest Service Technology and Development Program Report No. 9034-2807.

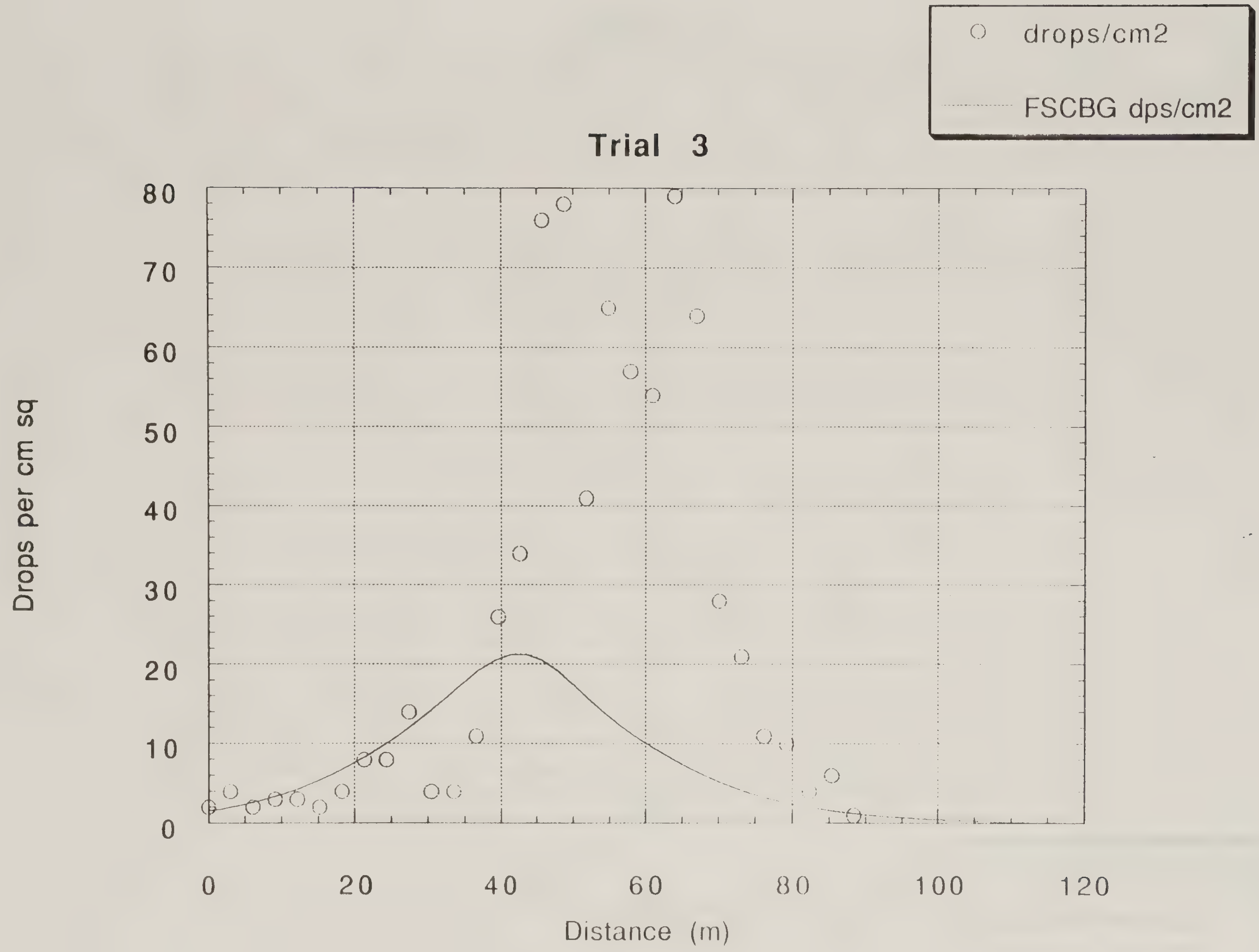
Appendix

The Appendix contains a plot of drops per square centimeter for each of the forty four Davis spray trials (1-45, with no trial 41). Data is shown as open circles; FSCBG predictions as solid lines.

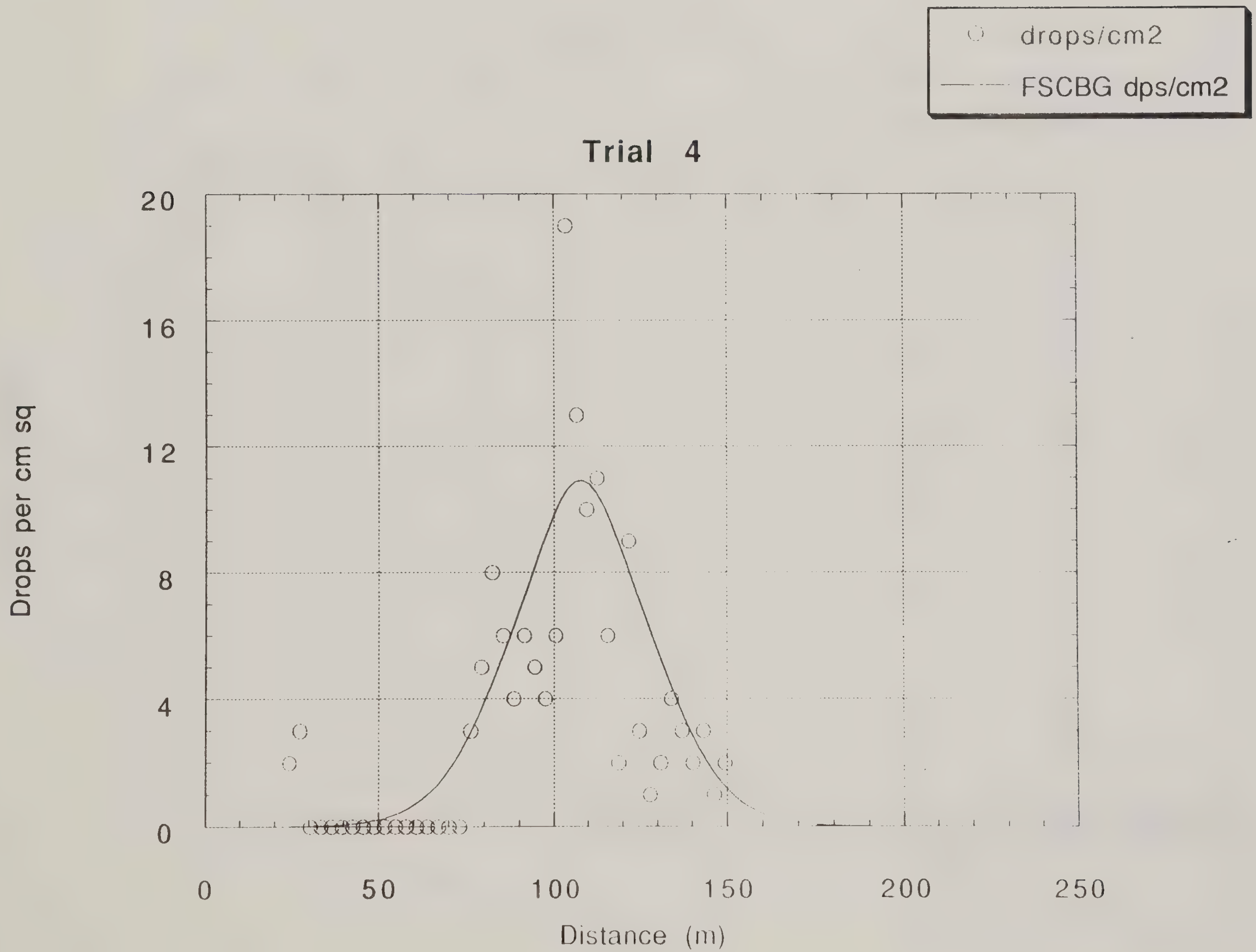

drops/cm2
FSCBG dps/cm2
Trial 1
Drops per cm sq
30
25
20
15
10
5
0
0
45
90
135
180
Distance (m)



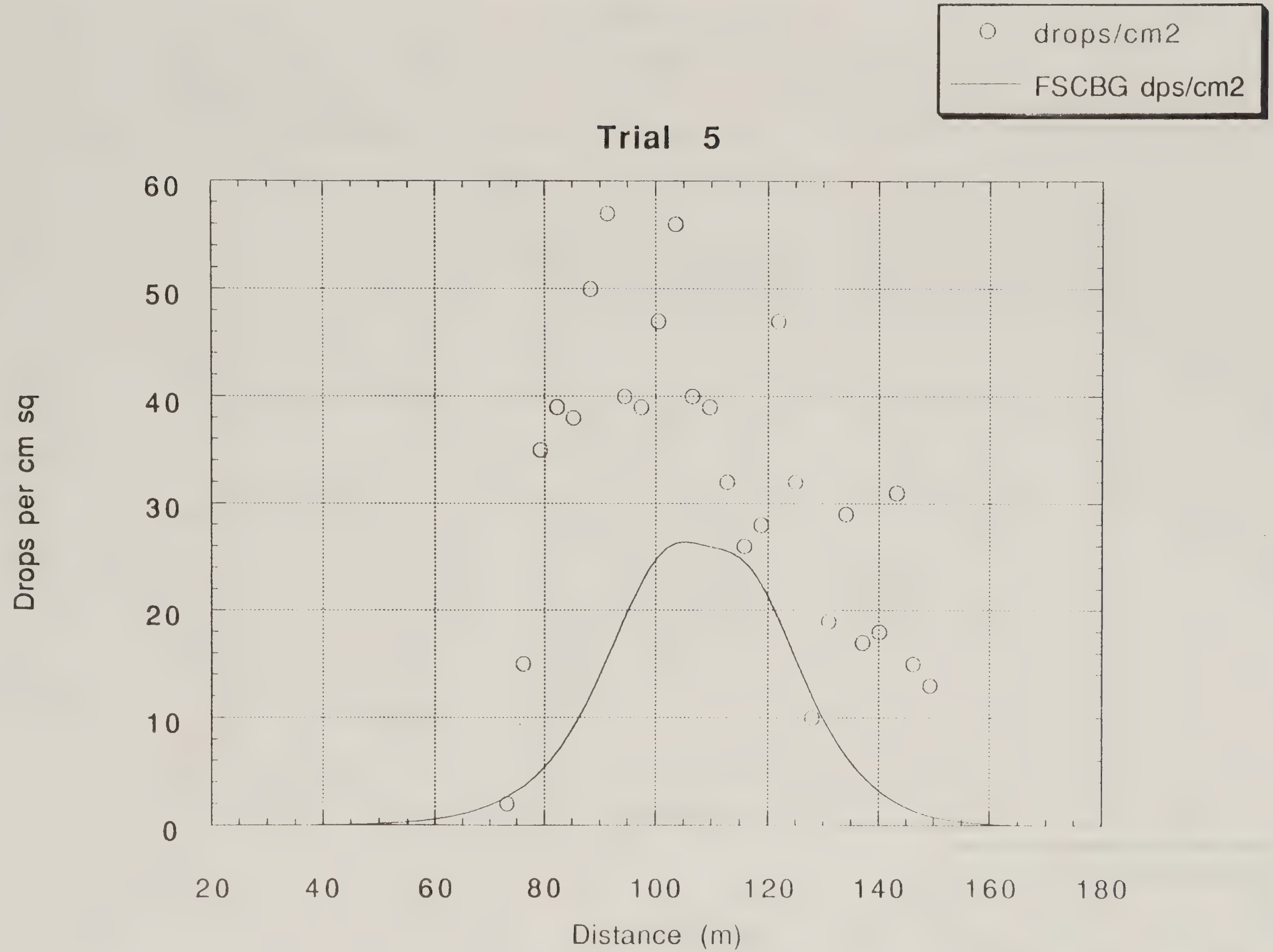
drops/cm2
FSCBG dps/cm2
Trial 2
Drops per cm sq
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
120
140
Distance (m)



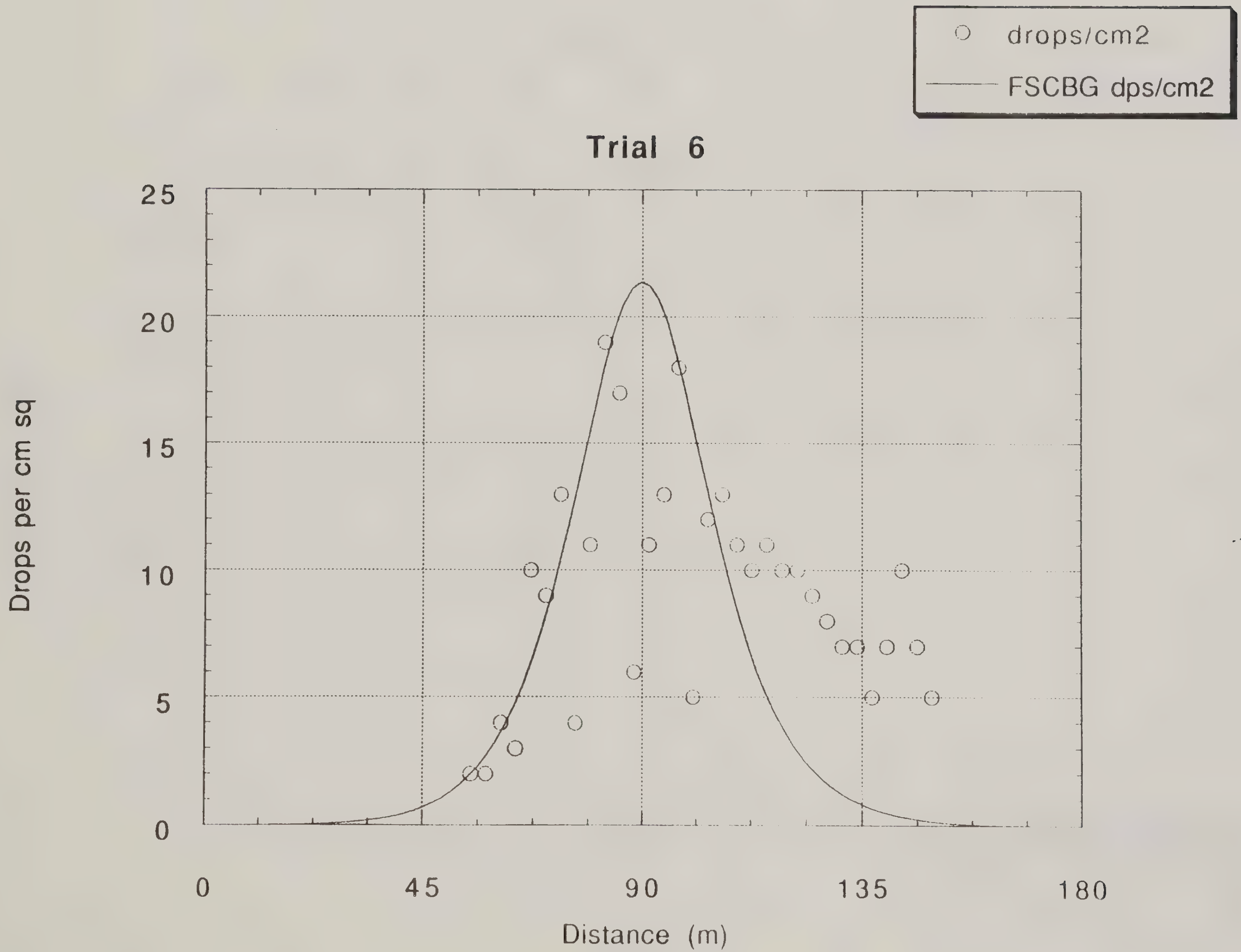
drops/cm2
FSCBG dps/cm2
Trial 3
Drops per cm sq
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
Distance (m)



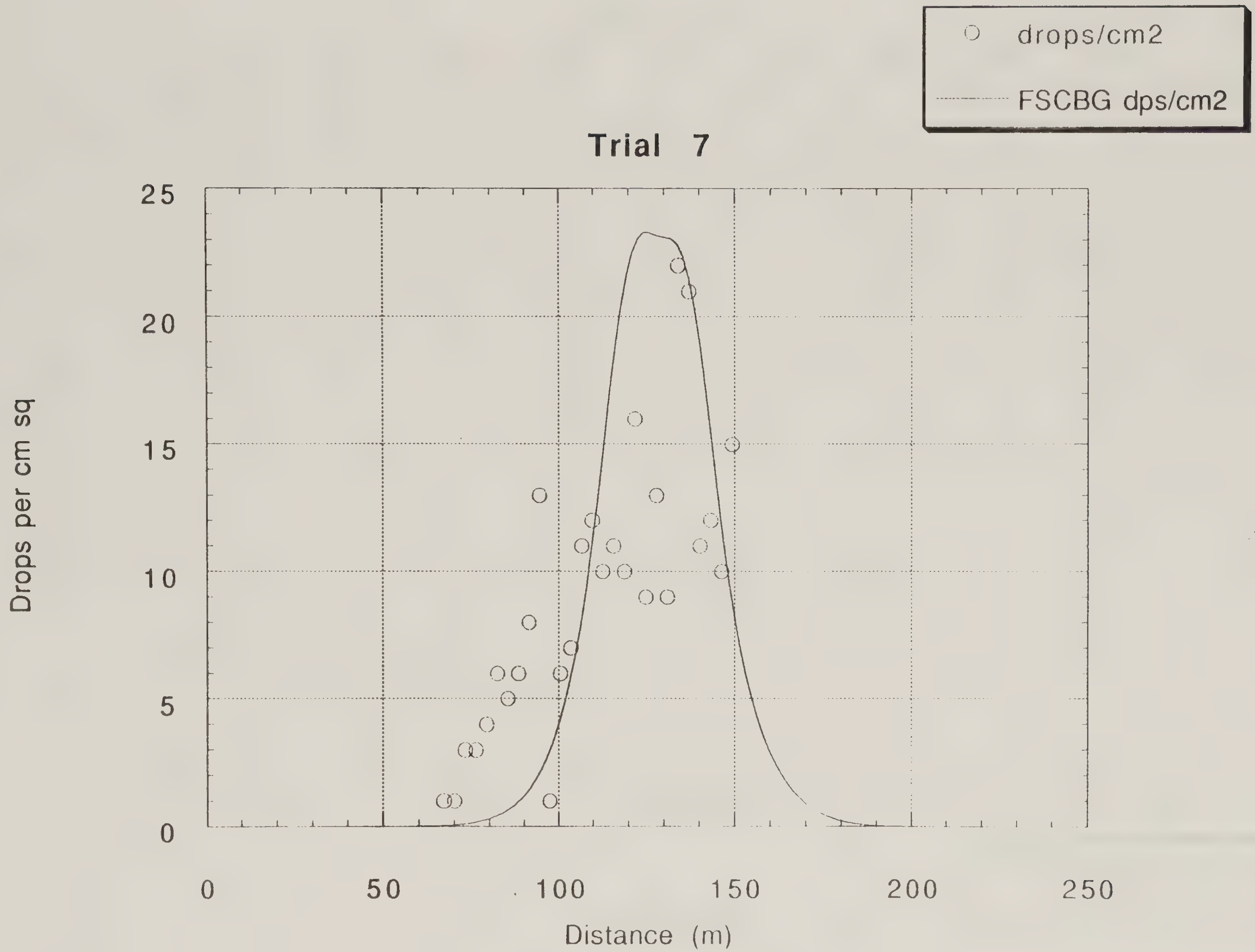
drops/cm2
FSCBG dps/cm2
Trial 4
Drops per cm sq
20
16
12
8
4
0
0
50
100
150
200
250
Distance (m)



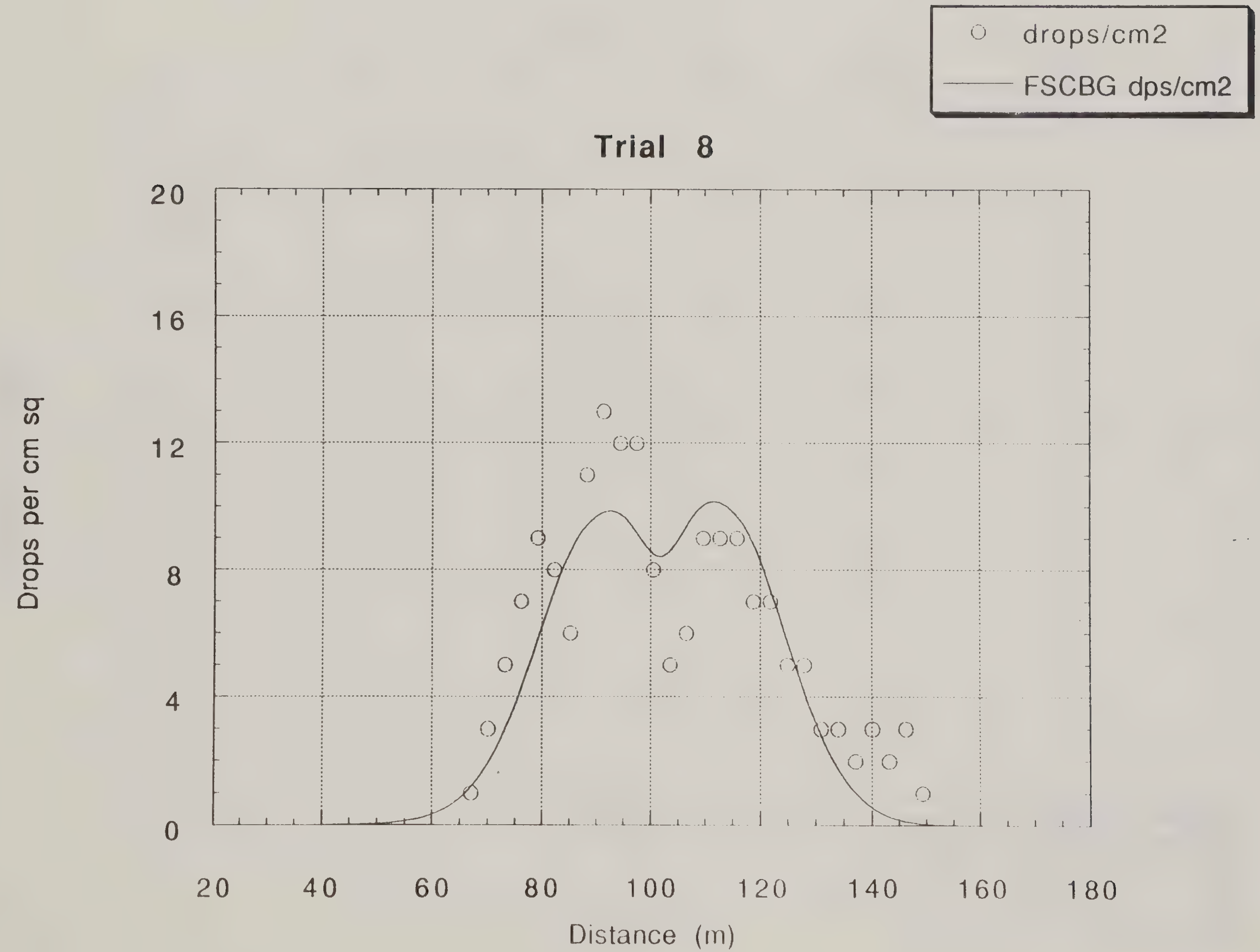
drops/cm2
FSCBG dps/cm2
Trial 5
Drops per cm sq
Distance (m)
0
10
20
30
40
50
60
20
40
60
80
100
120
140
160
180

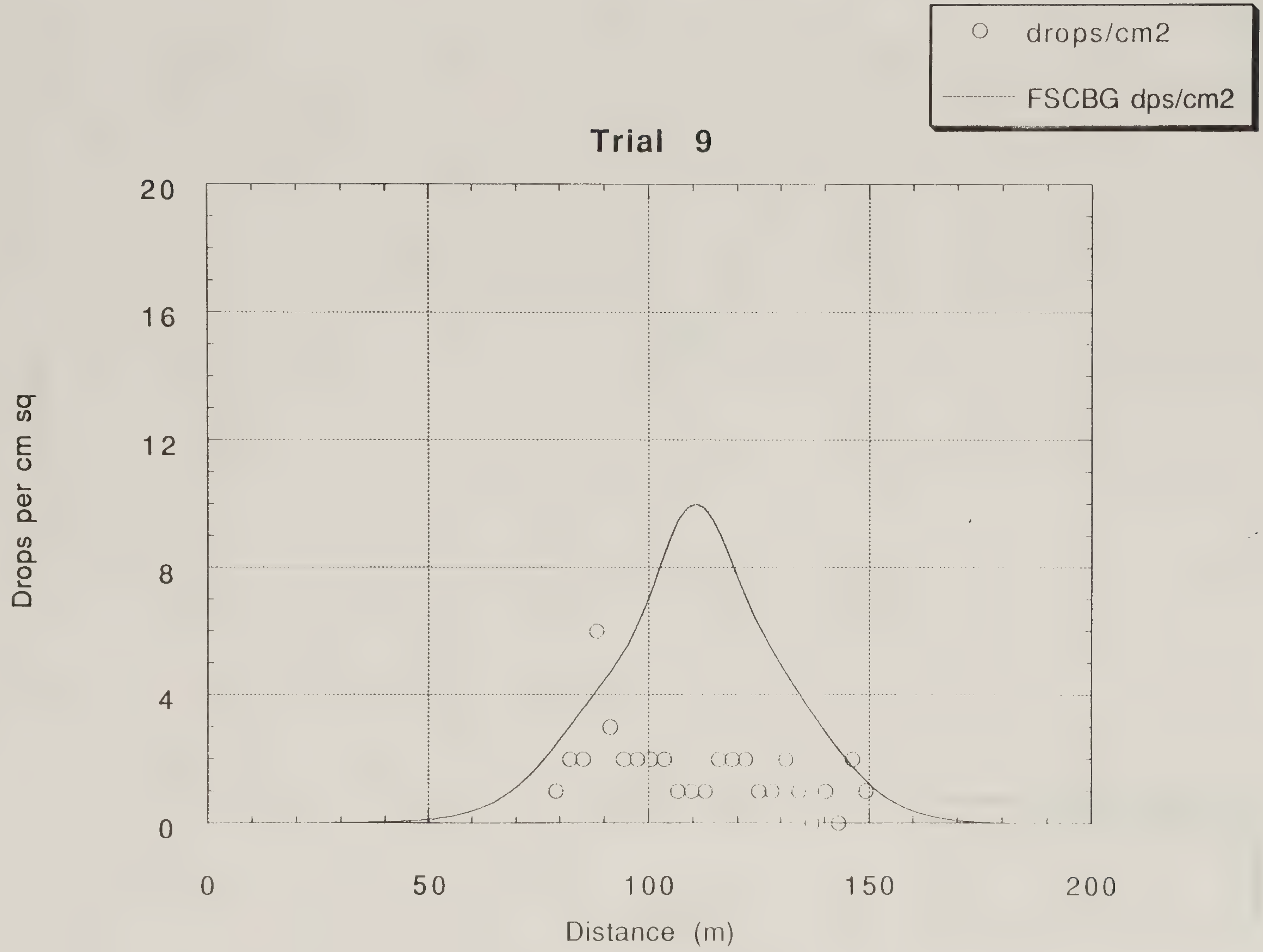


drops/cm2
FSCBG dps/cm2
Trial 6
Drops per cm sq
25
20
15
10
5
0
0
45
90
135
180
Distance (m)

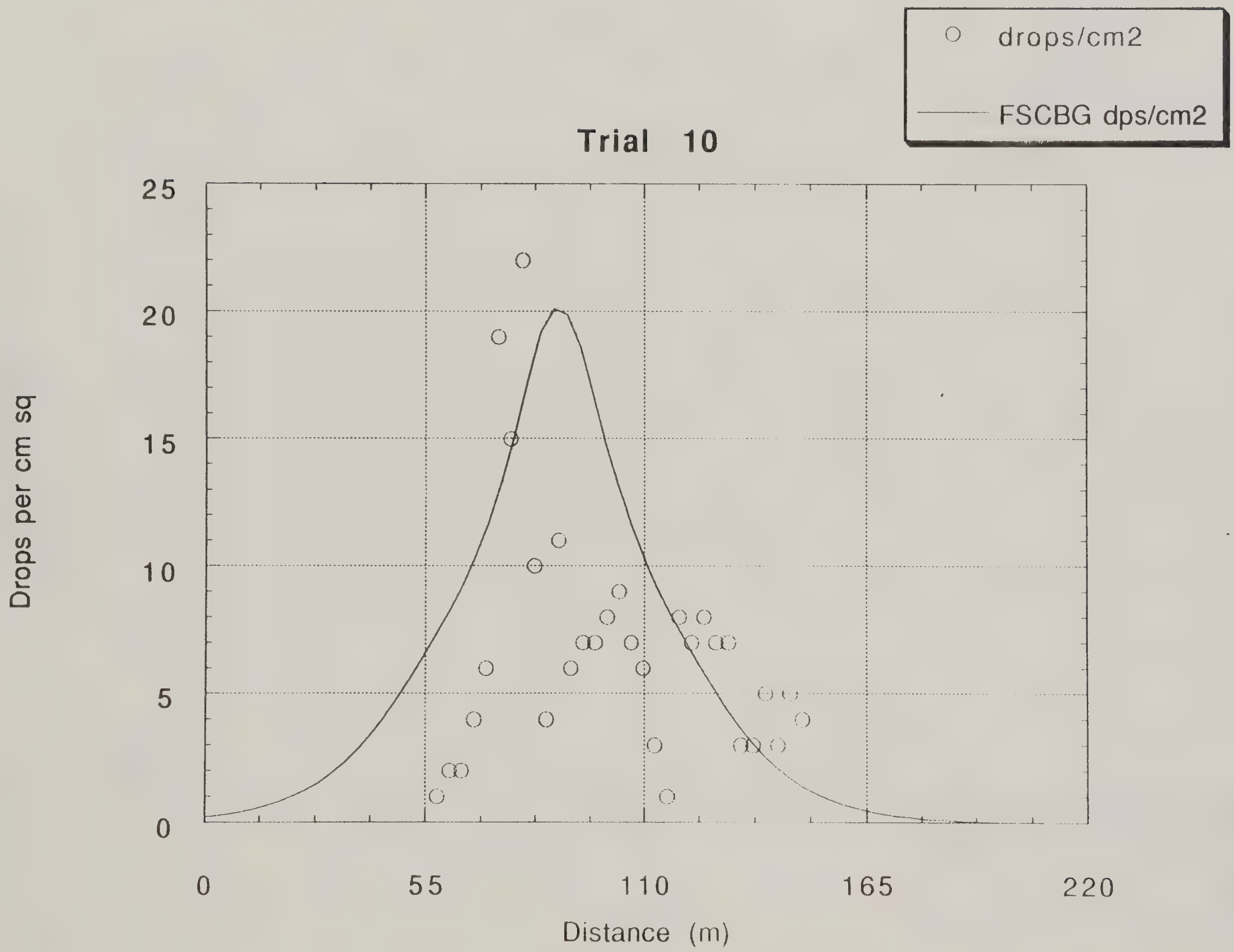


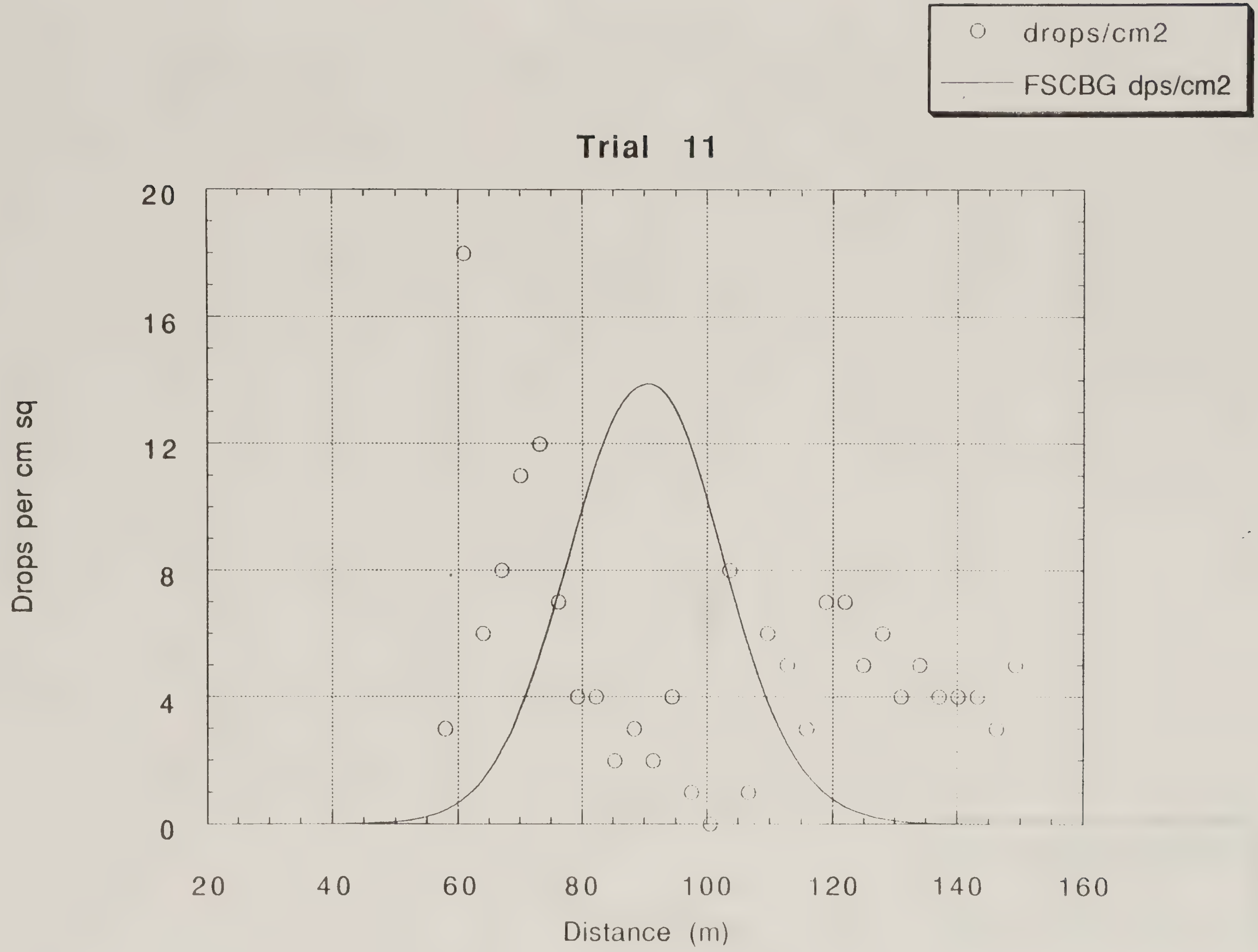
drops/cm2
FSCBG dps/cm2
Trial 7
25
20
15
10
5
0
Drops per cm sq
0
50
100
150
200
250
Distance (m)


drops/cm2
FSCBG dps/cm2
Trial 8
20
16
12
8
4
0
Drops per cm sq
20
40
60
80
100
120
140
160
180
Distance (m)

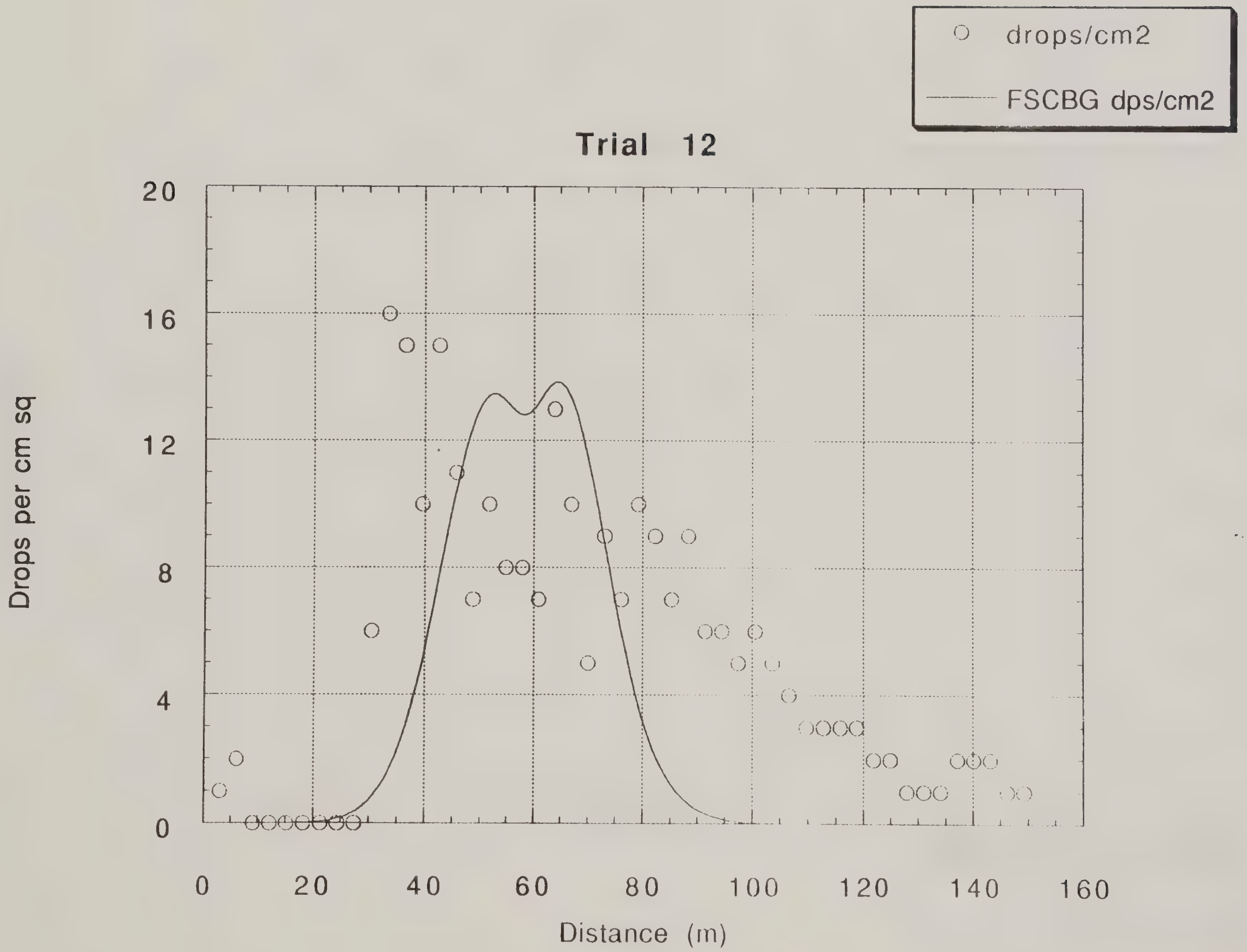


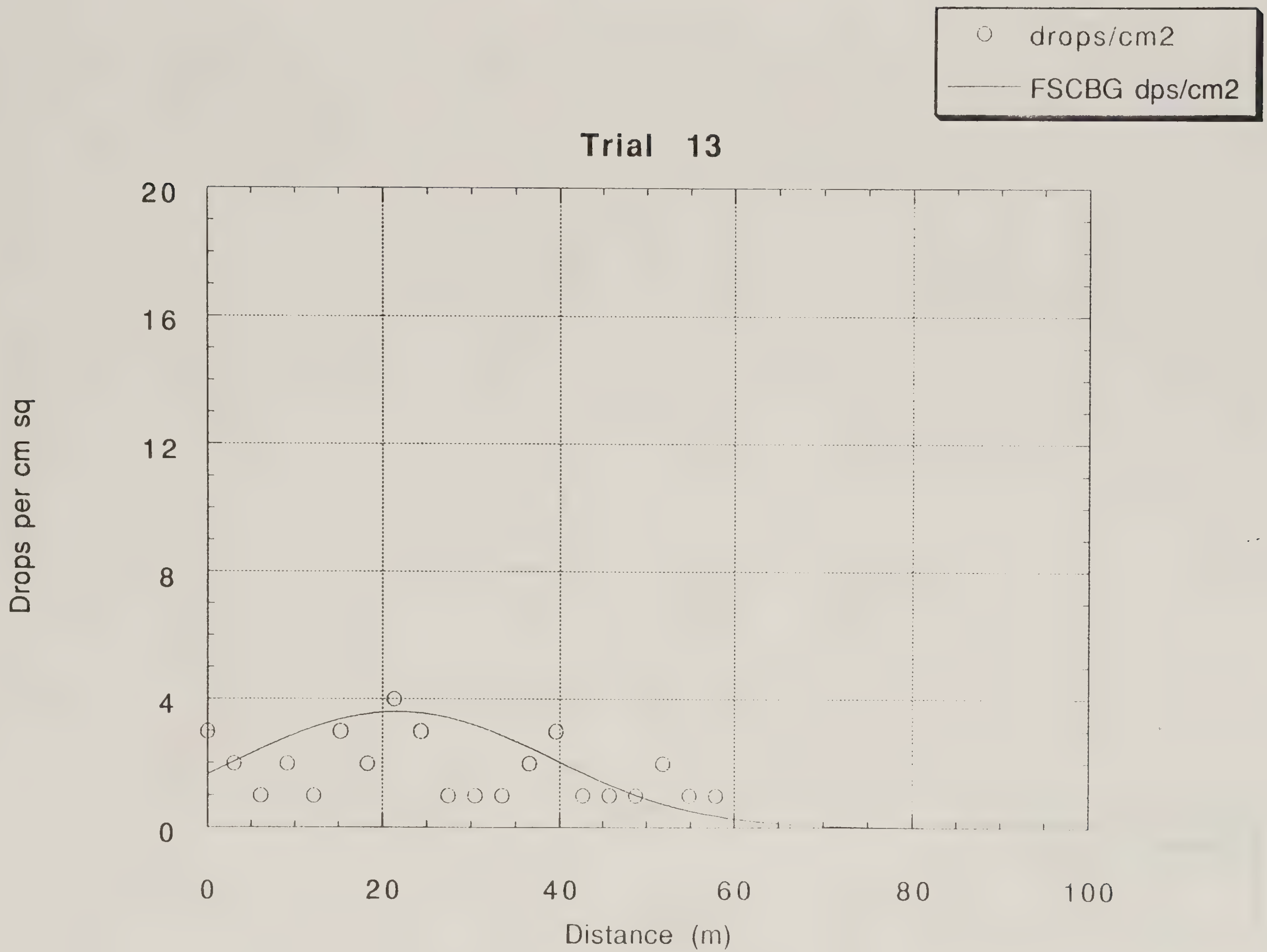
Trial 9
drops/cm2
FSCBG dps/cm2
Drops per cm sq
Distance (m)
0
4
8
12
16
20
0
50
100
150
200

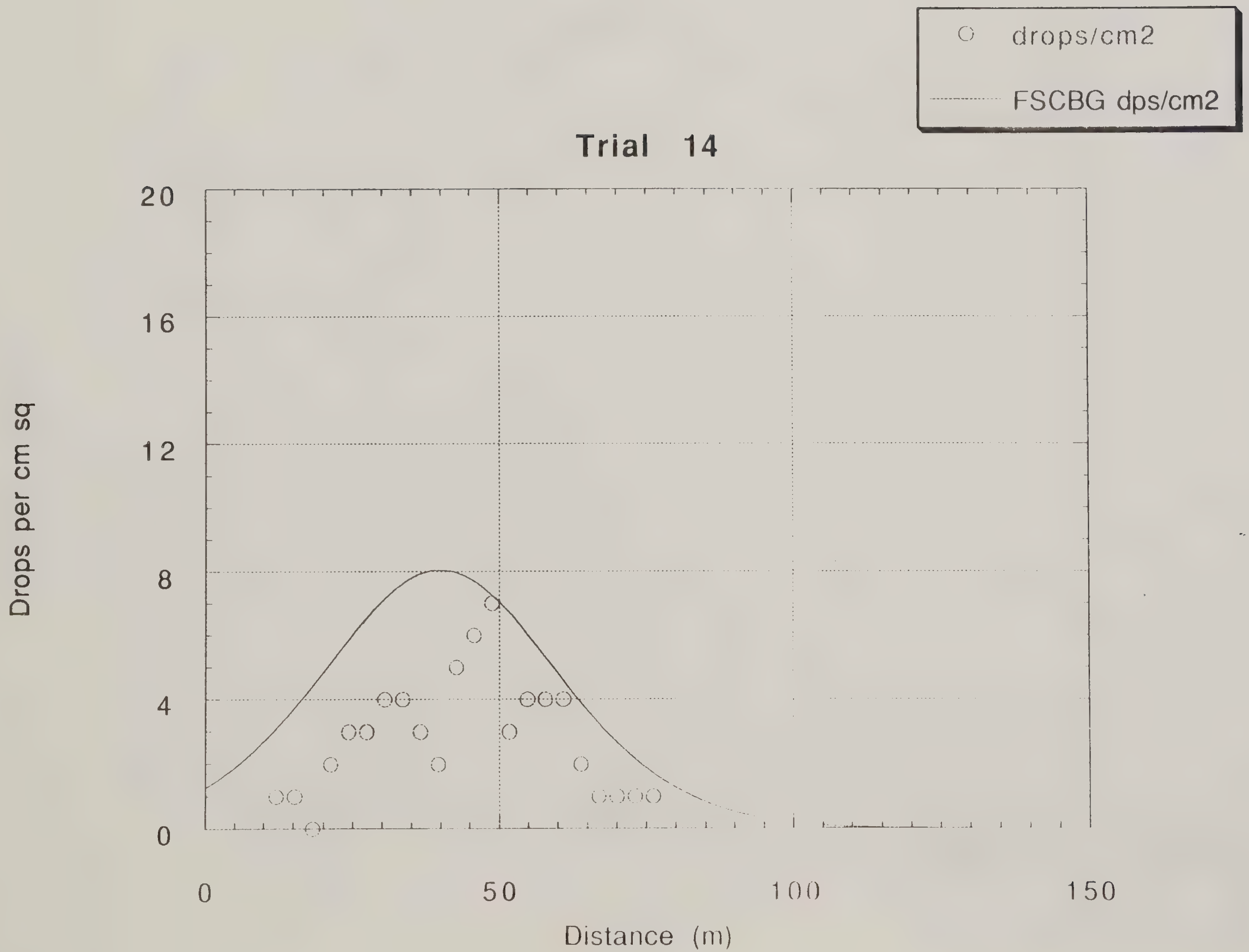

Trial 10
drops/cm2
FSCBG dps/cm2
Drops per cm sq
0
5
10
15
20
25
0
55
110
165
220
Distance (m)

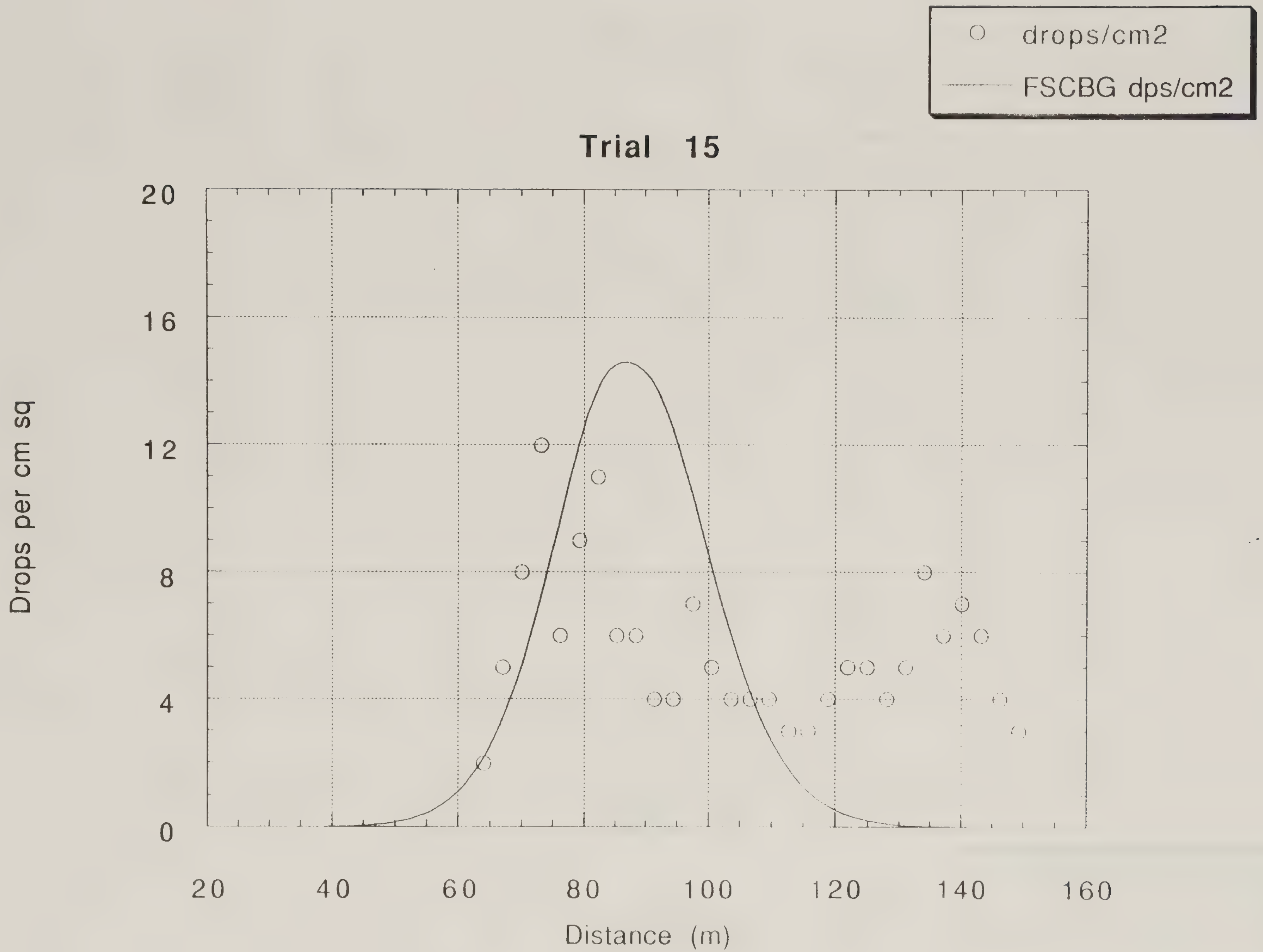


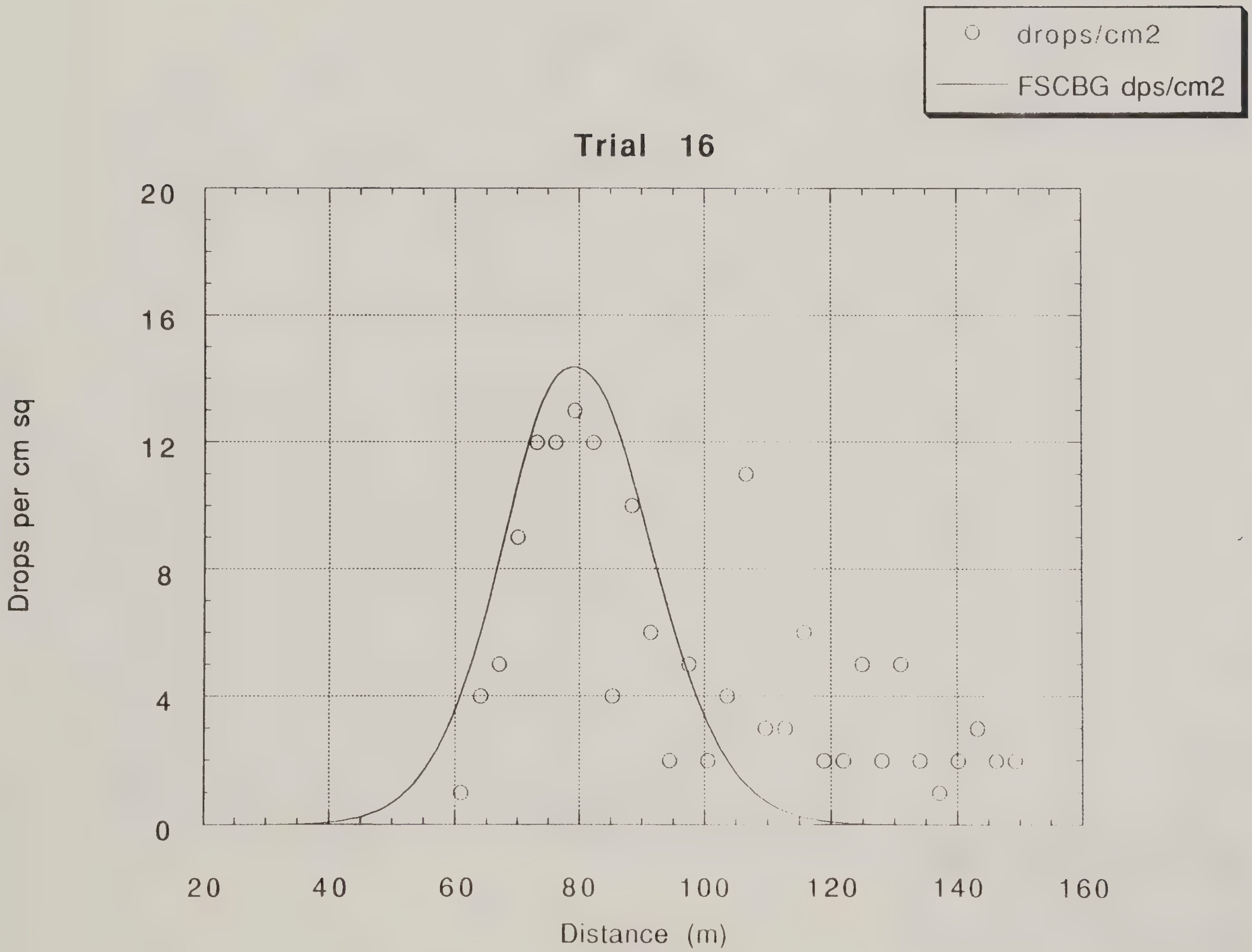
drops/cm2
FSCBG dps/cm2
Trial 11
Drops per cm sq
Distance (m)
0
4
8
12
16
20
20
40
60
80
100
120
140
160


drops/cm2
FSCBG dps/cm2
Trial 12
Drops per cm sq
0
4
8
12
16
20
0
20
40
60
80
100
120
140
160
Distance (m)

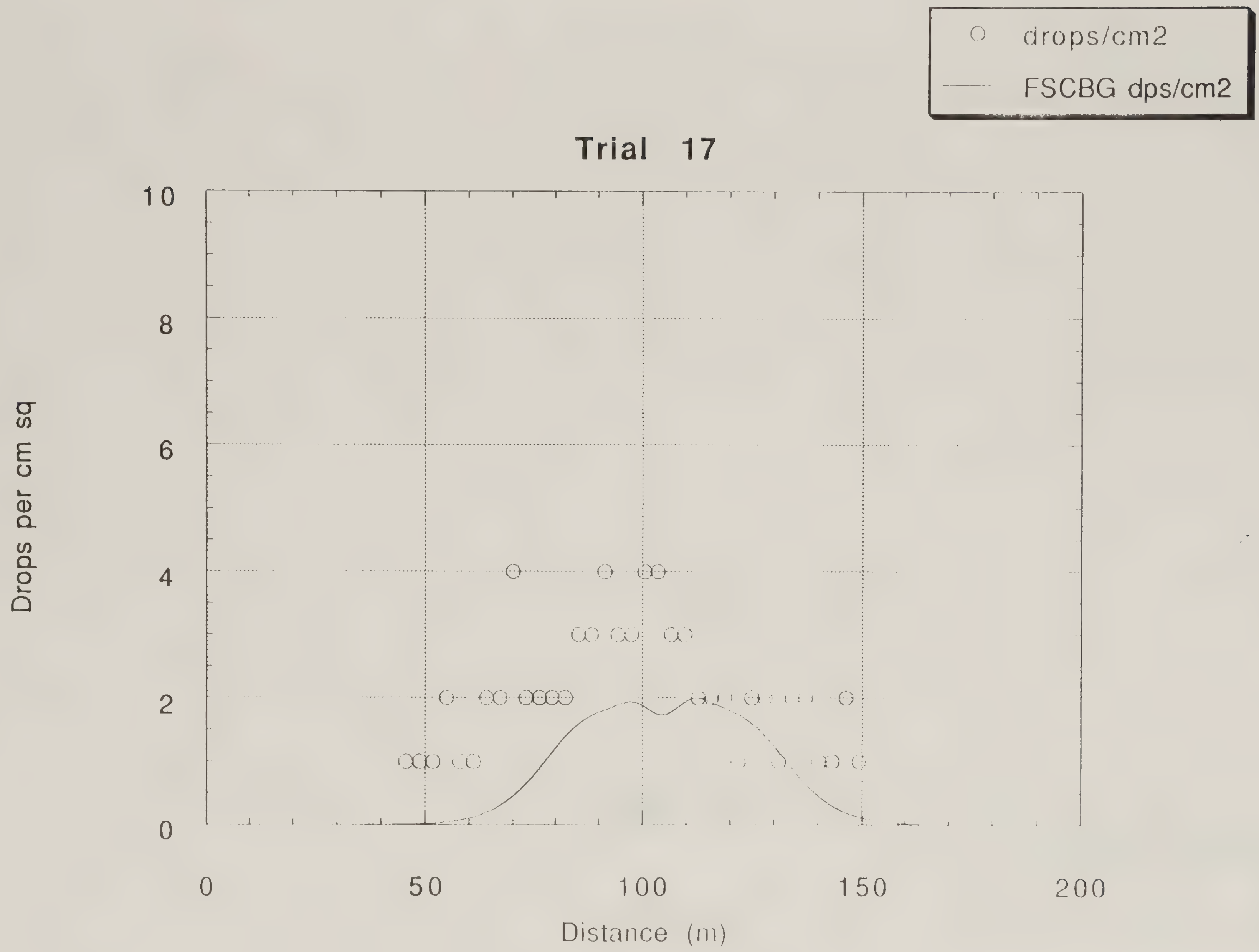

drops/cm2
FSCBG dps/cm2
Trial 13
20
16
12
8
4
0
0
20
40
60
80
100
Distance (m)
Drops per cm sq


Trial 14
drops/cm2
FSCBG dps/cm2
Drops per cm sq
20
16
12
8
4
0
0
50
100
150
Distance (m)

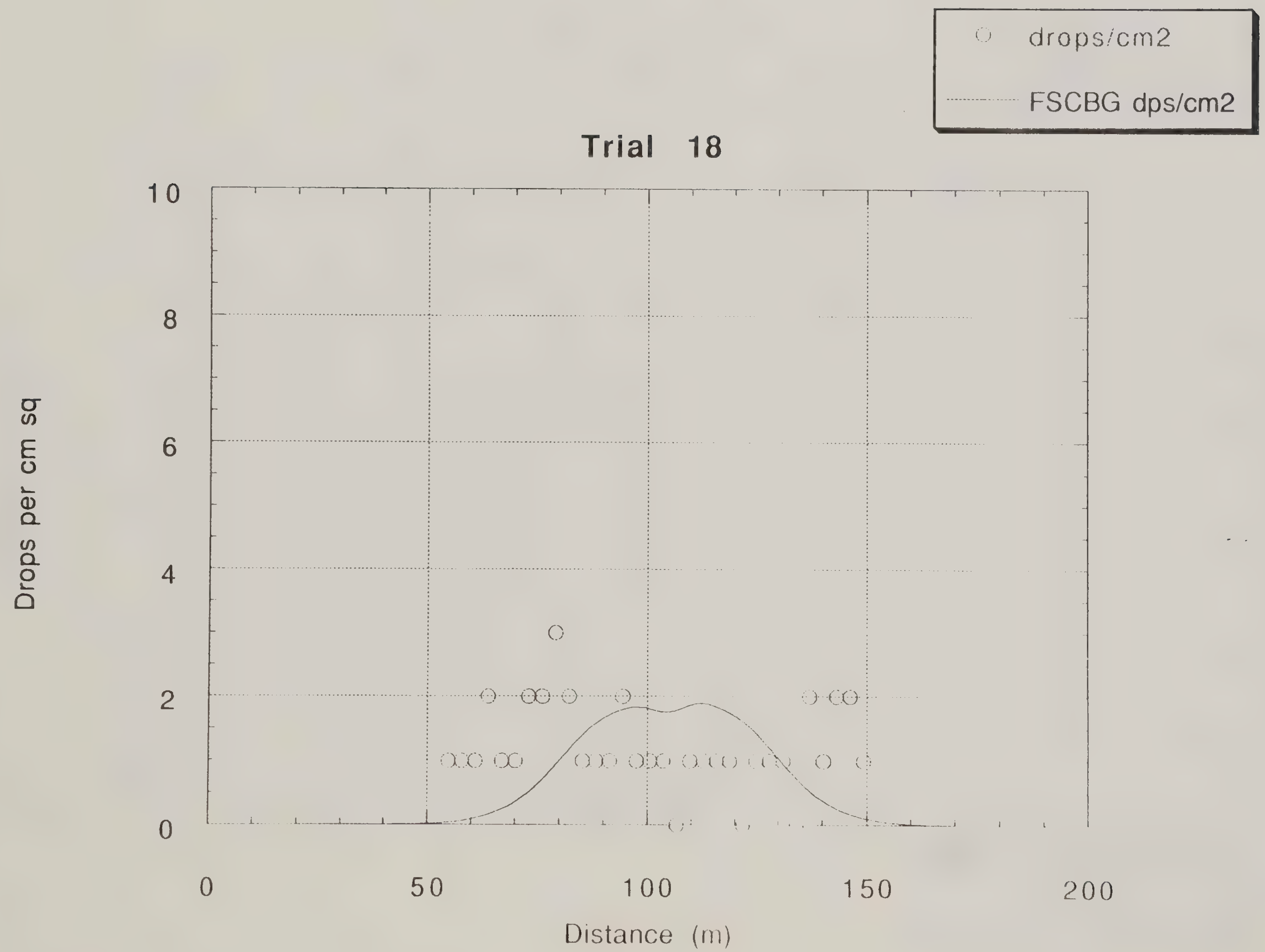

drops/cm2
FSCBG dps/cm2
Trial 15
Drops per cm sq
0
4
8
12
16
20
20
40
60
80
100
120
140
160
Distance (m)



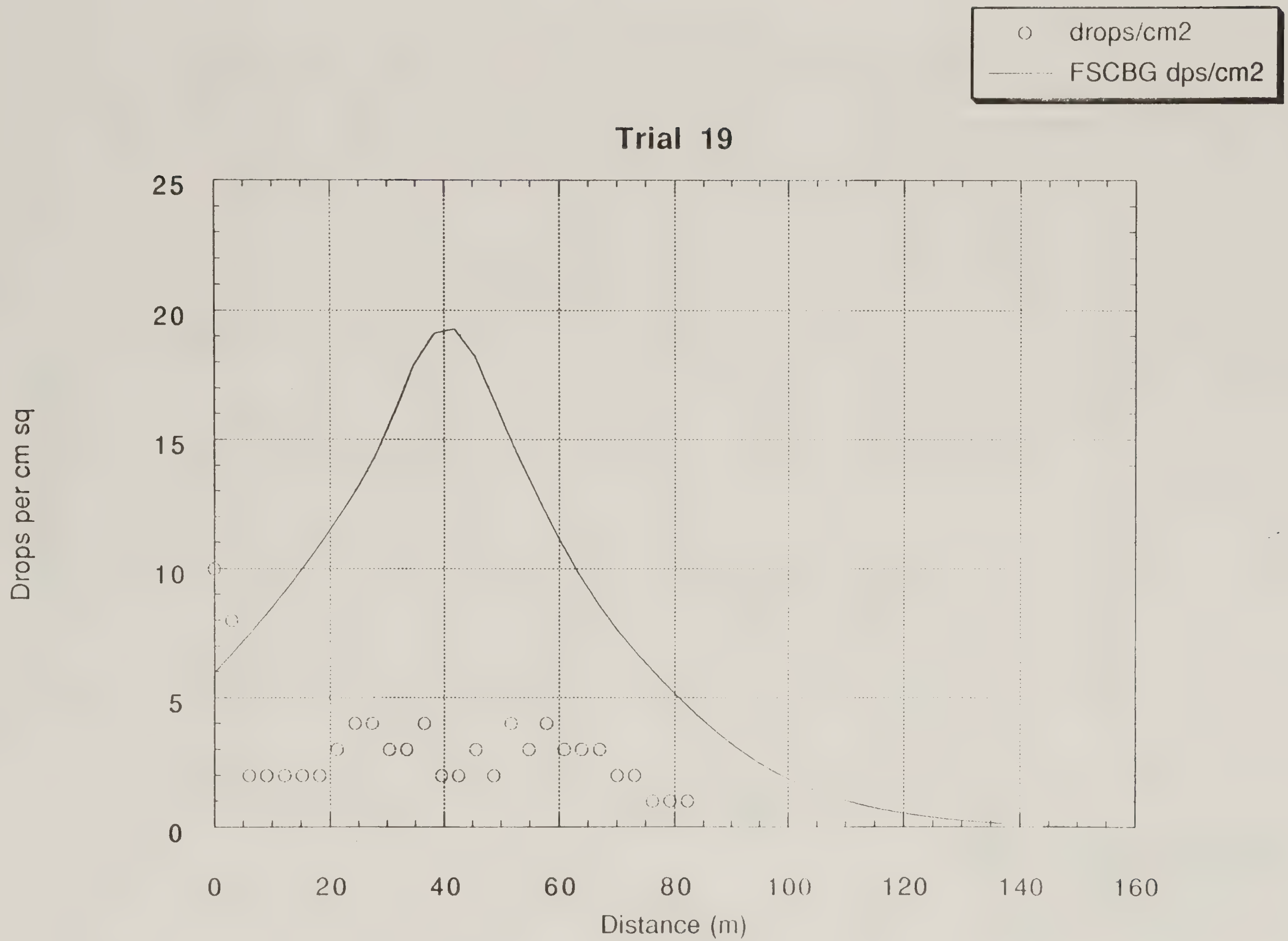
drops/cm2
FSCBG dps/cm2
Trial 16
Drops per cm sq
20
16
12
8
4
0
20
40
60
80
100
120
140
160
Distance (m)



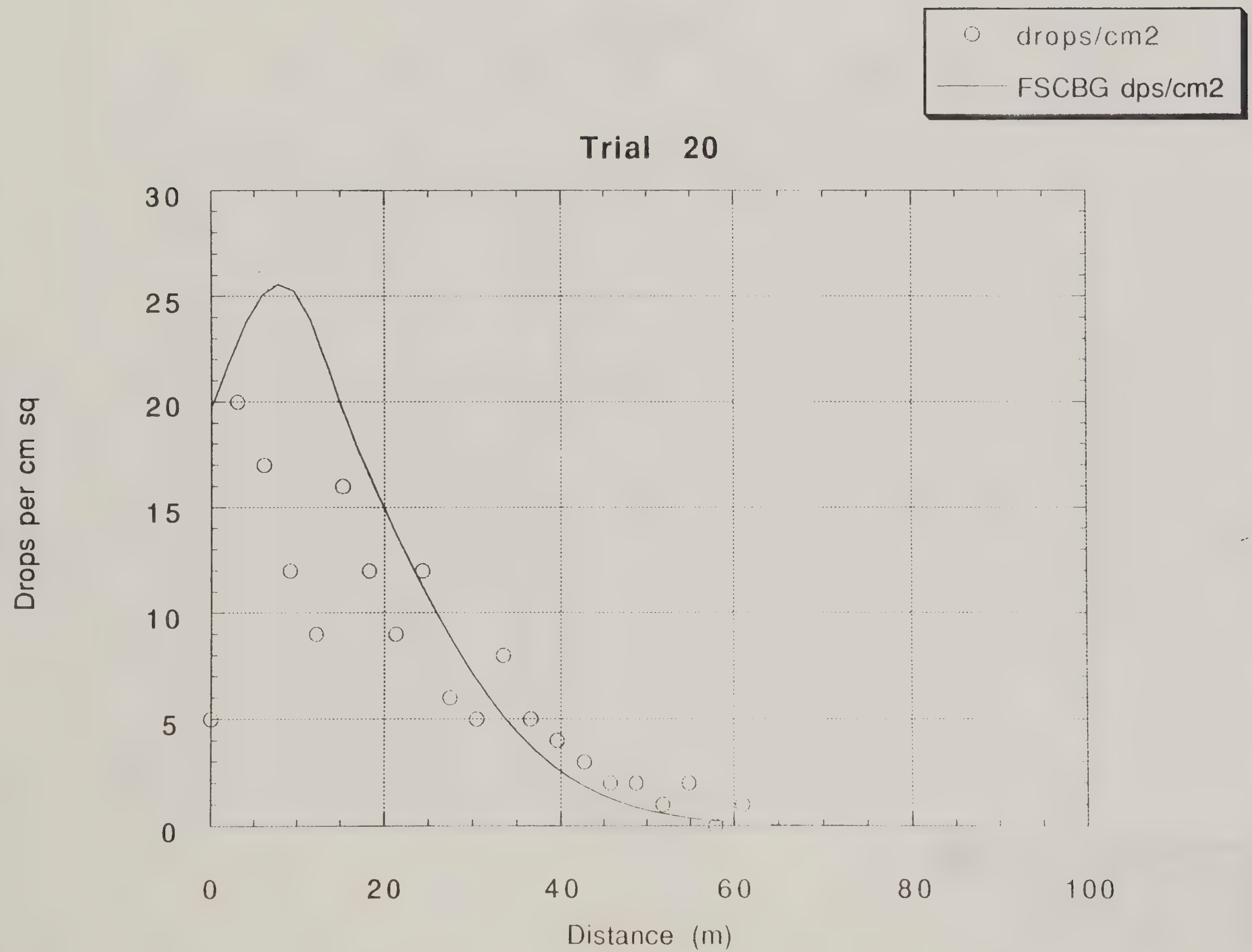
drops/cm2
FSCBG dps/cm2
Trial 17
10
8
6
4
2
0
Drops per cm sq
0
50
100
150
200
Distance (m)



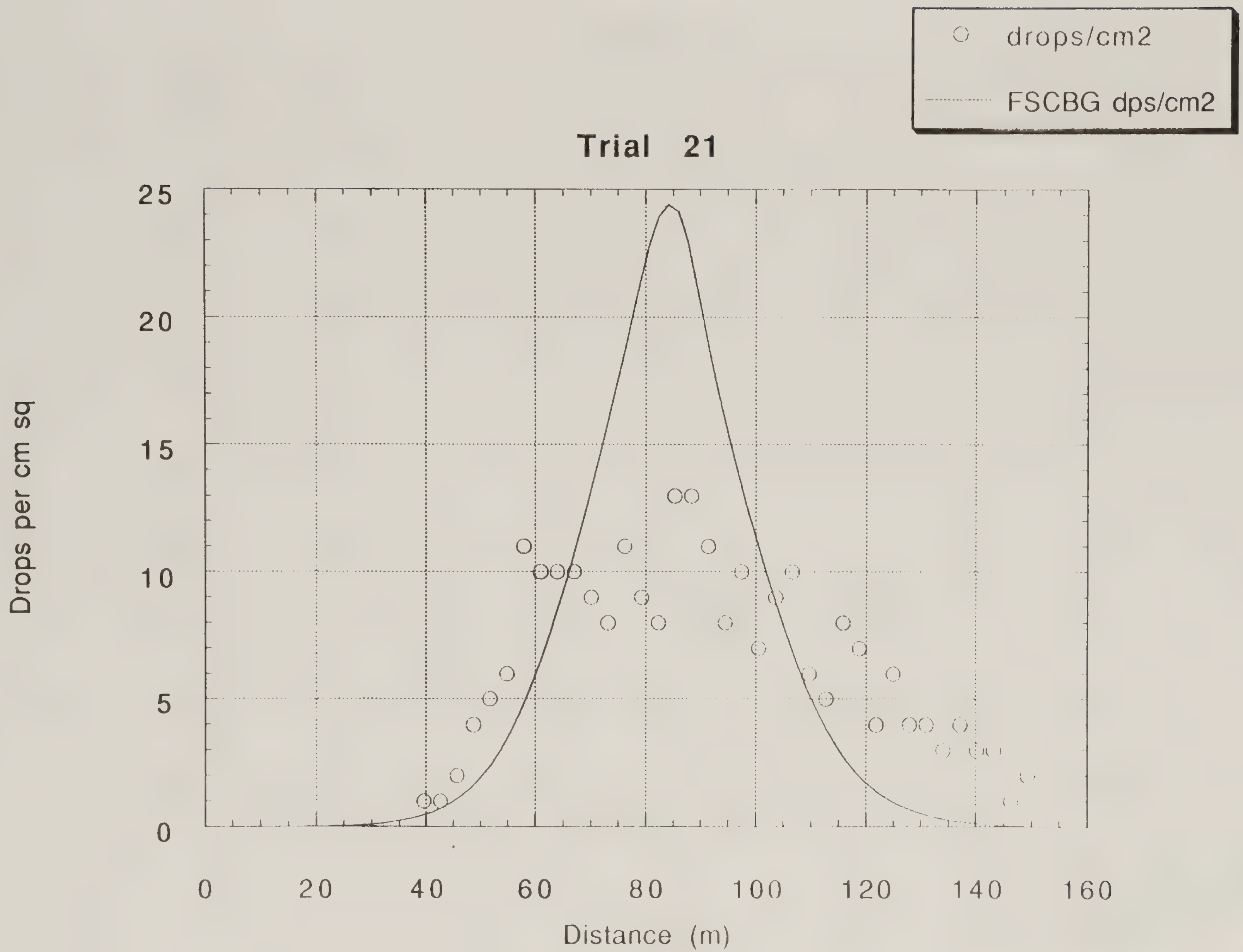
Trial 18
drops/cm2
FSCBG dps/cm2
Drops per cm sq
Distance (m)
0
2
4
6
8
10
0
50
100
150
200



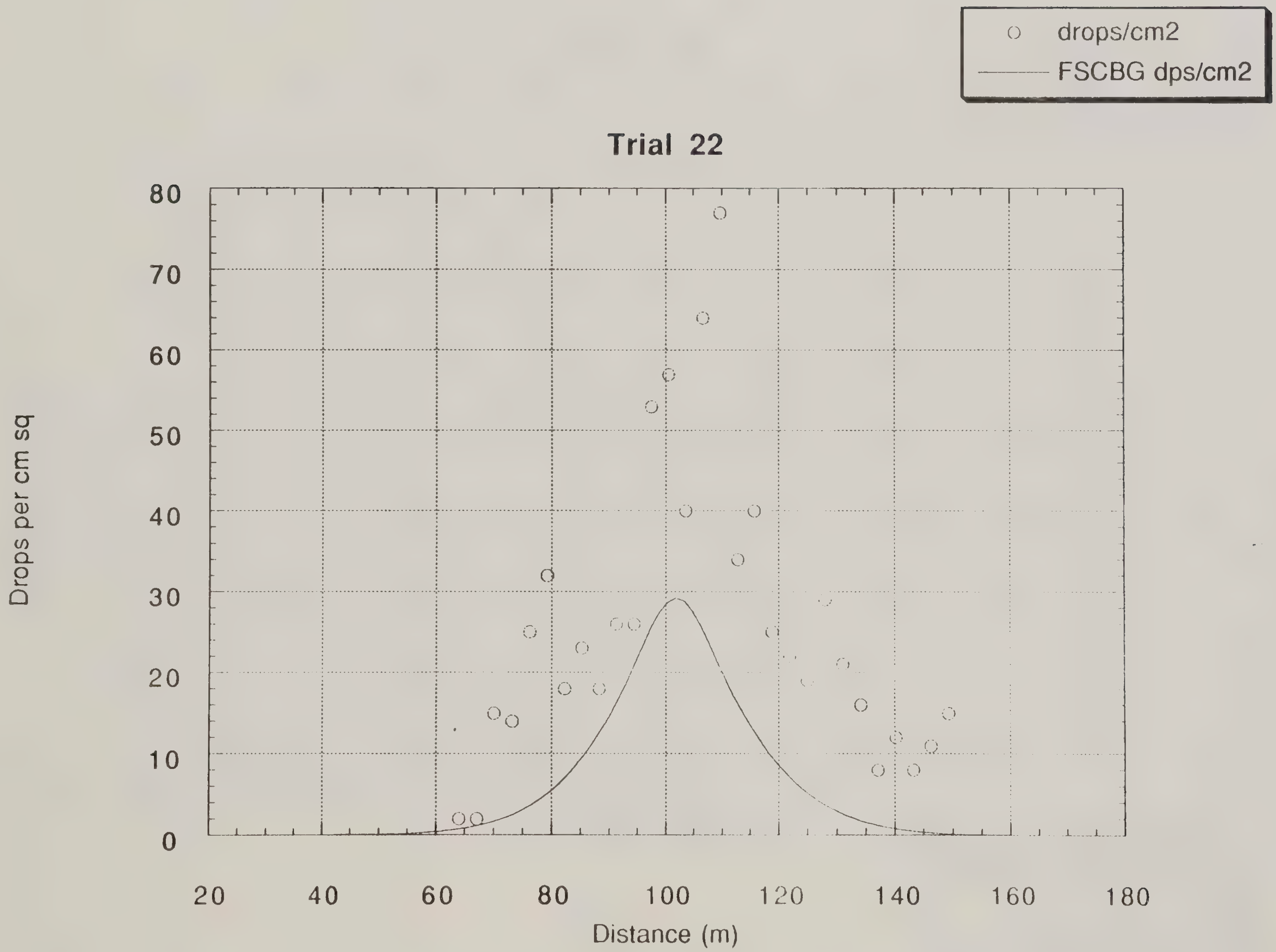
drops/cm2
FSCBG dps/cm2
Trial 19
Drops per cm sq
25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
Distance (m)

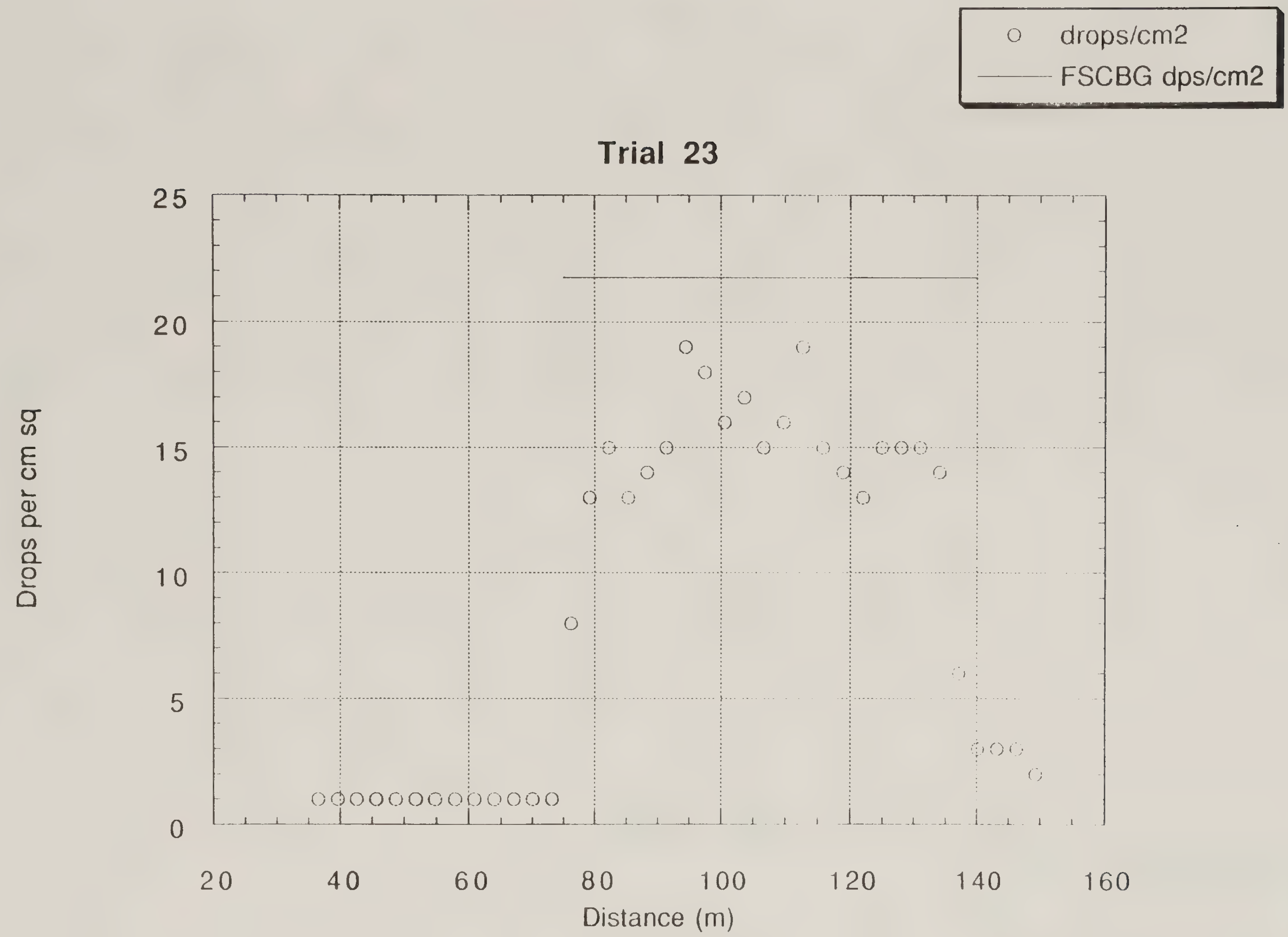


drops/cm2
FSCBG dps/cm2
Trial 20
30
25
20
15
10
5
0
Drops per cm sq
0
20
40
60
80
100
Distance (m)

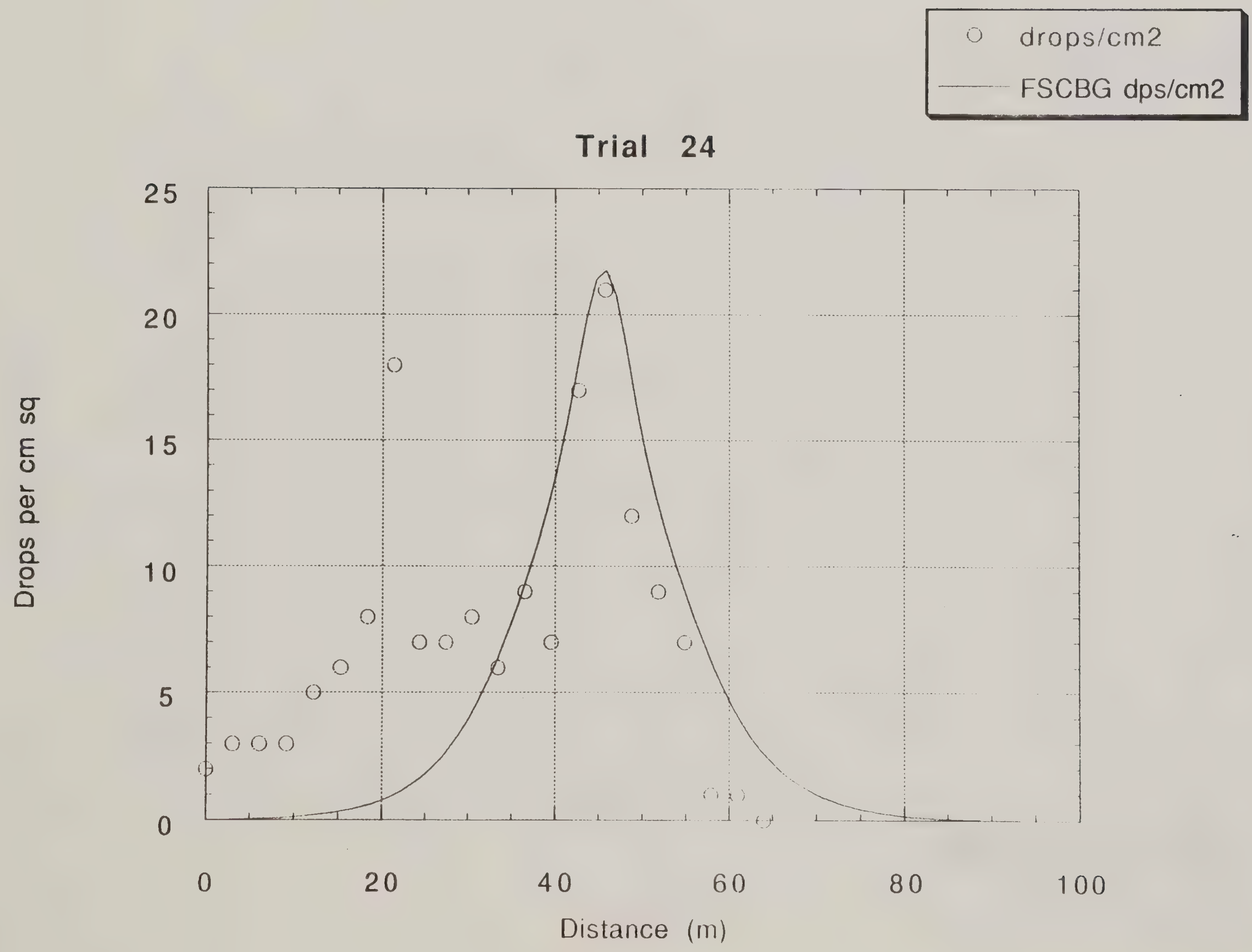


drops/cm2
FSCBG dps/cm2
Trial 21
25
20
15
10
5
0
Drops per cm sq
0
20
40
60
80
100
120
140
160
Distance (m)

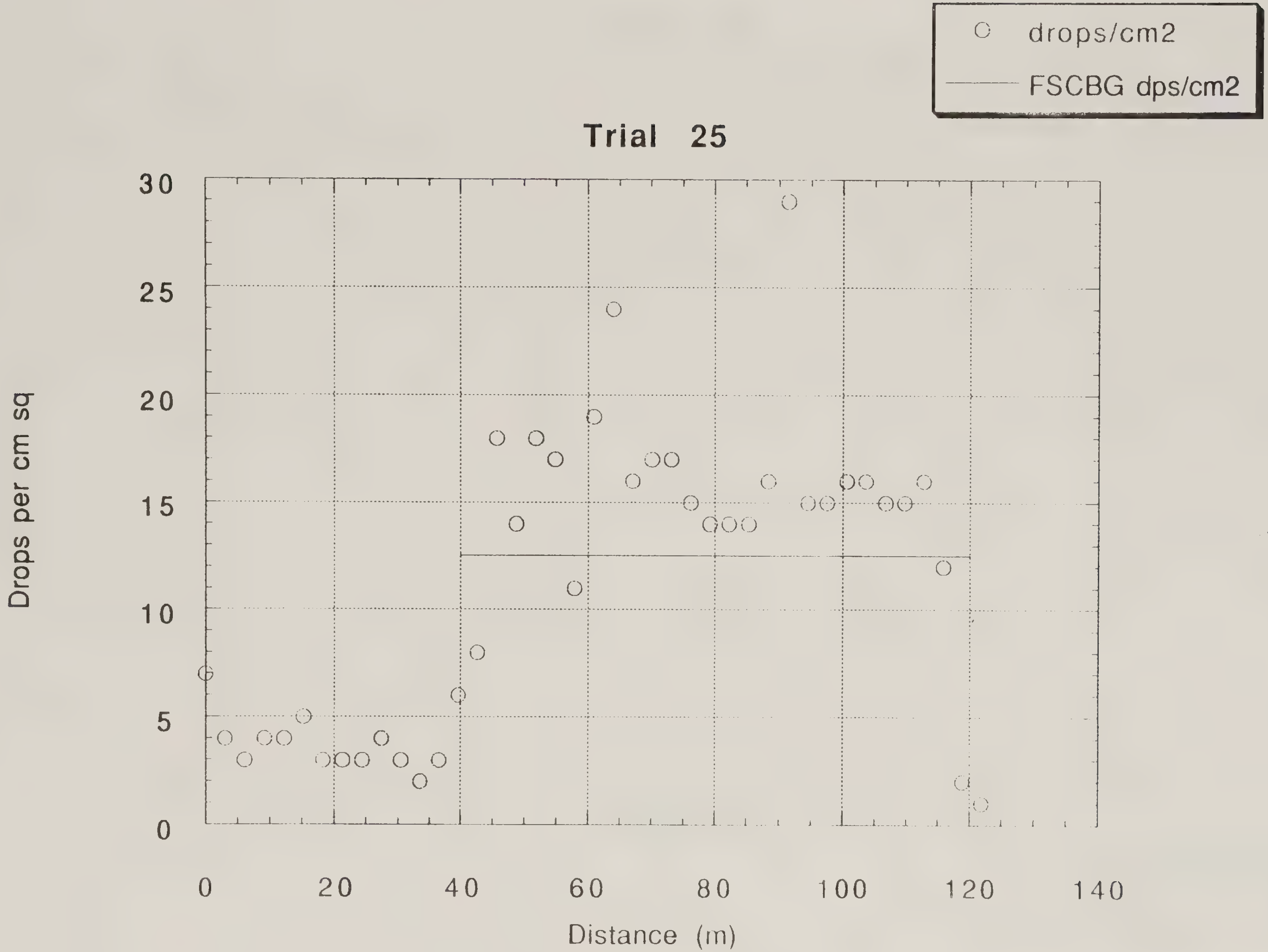

drops/cm2
FSCBG dps/cm2
Trial 22
80
70
60
50
40
30
20
10
0
Drops per cm sq
20
40
60
80
100
120
140
160
180
Distance (m)



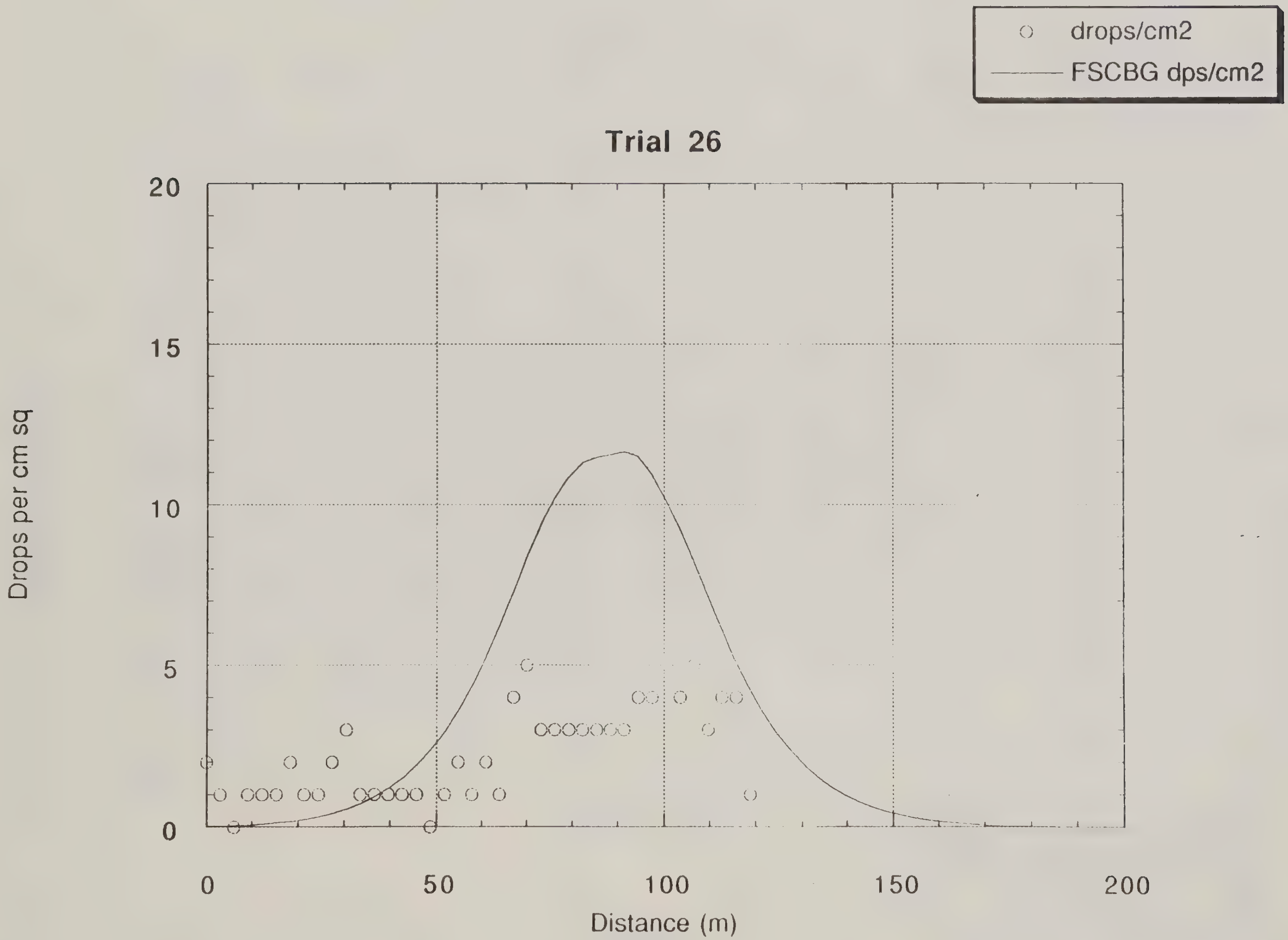
drops/cm2
FSCBG dps/cm2
Trial 23
25
20
15
10
5
0
20
40
60
80
100
120
140
160
Distance (m)
Drops per cm sq



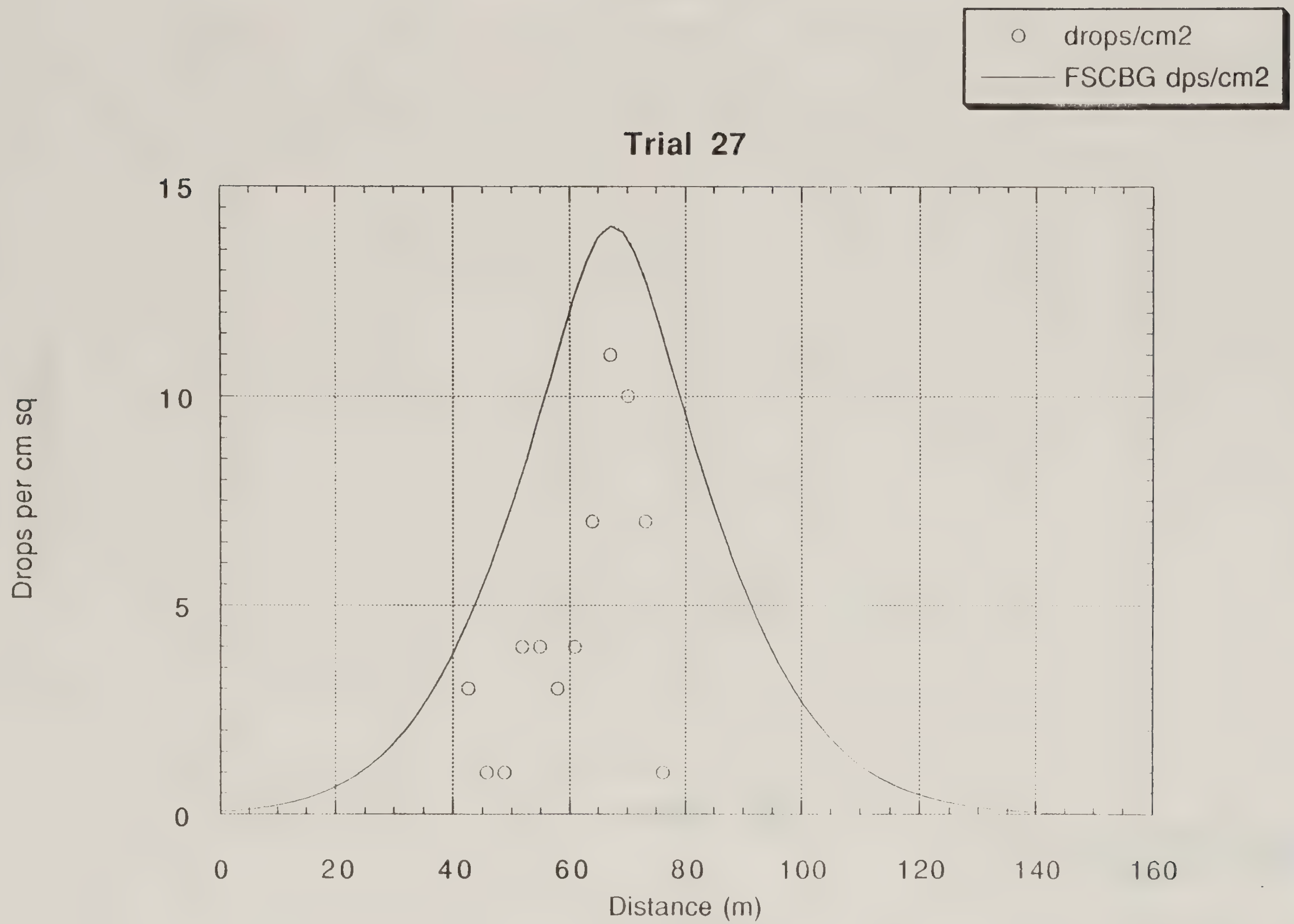
drops/cm2
FSCBG dps/cm2
Trial 24
25
20
15
10
5
0
0
20
40
60
80
100
Drops per cm sq
Distance (m)


drops/cm2
FSCBG dps/cm2
Trial 25
Drops per cm sq
30
25
20
15
10
5
0
0
20
40
60
80
100
120
140
Distance (m)

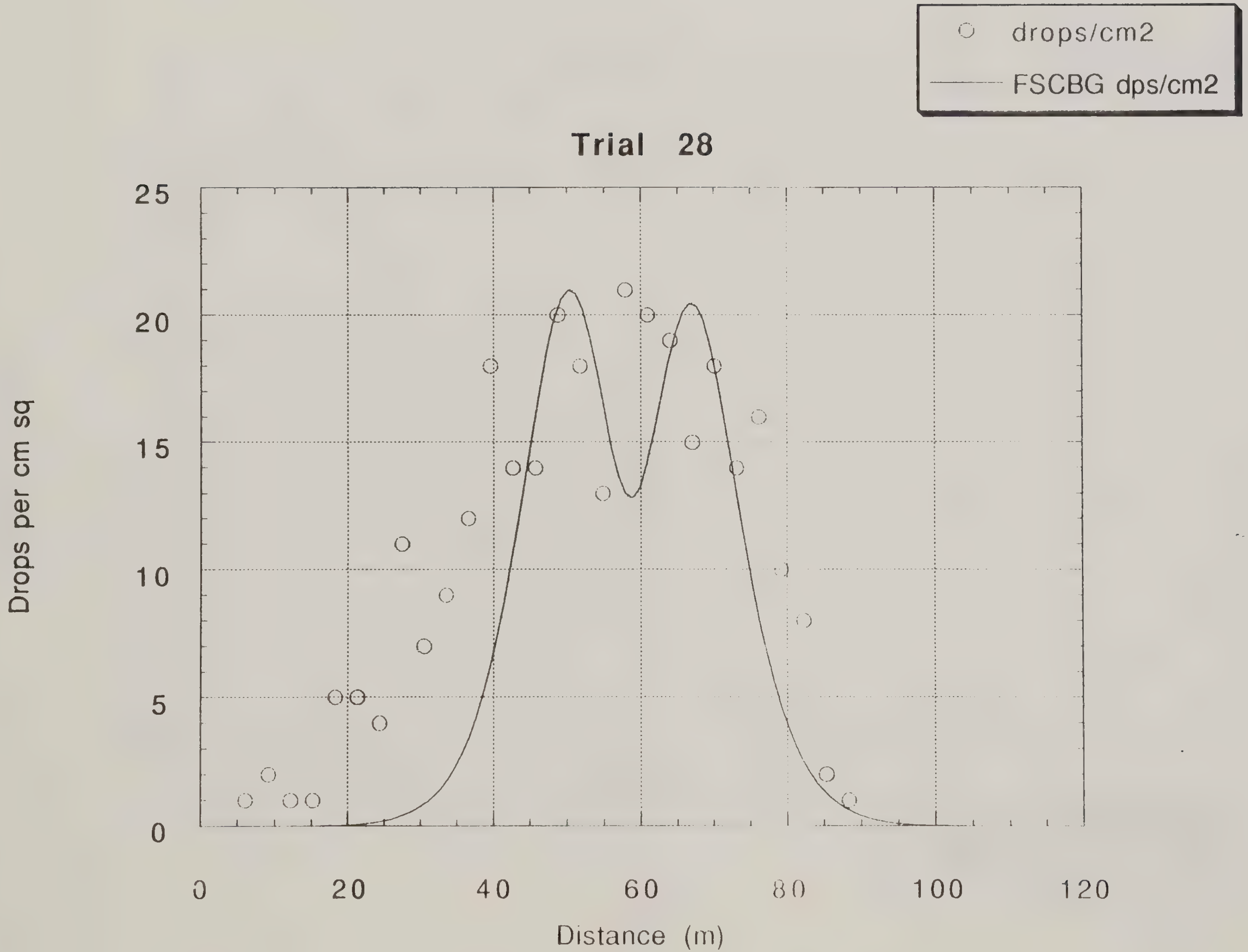
Trial 26

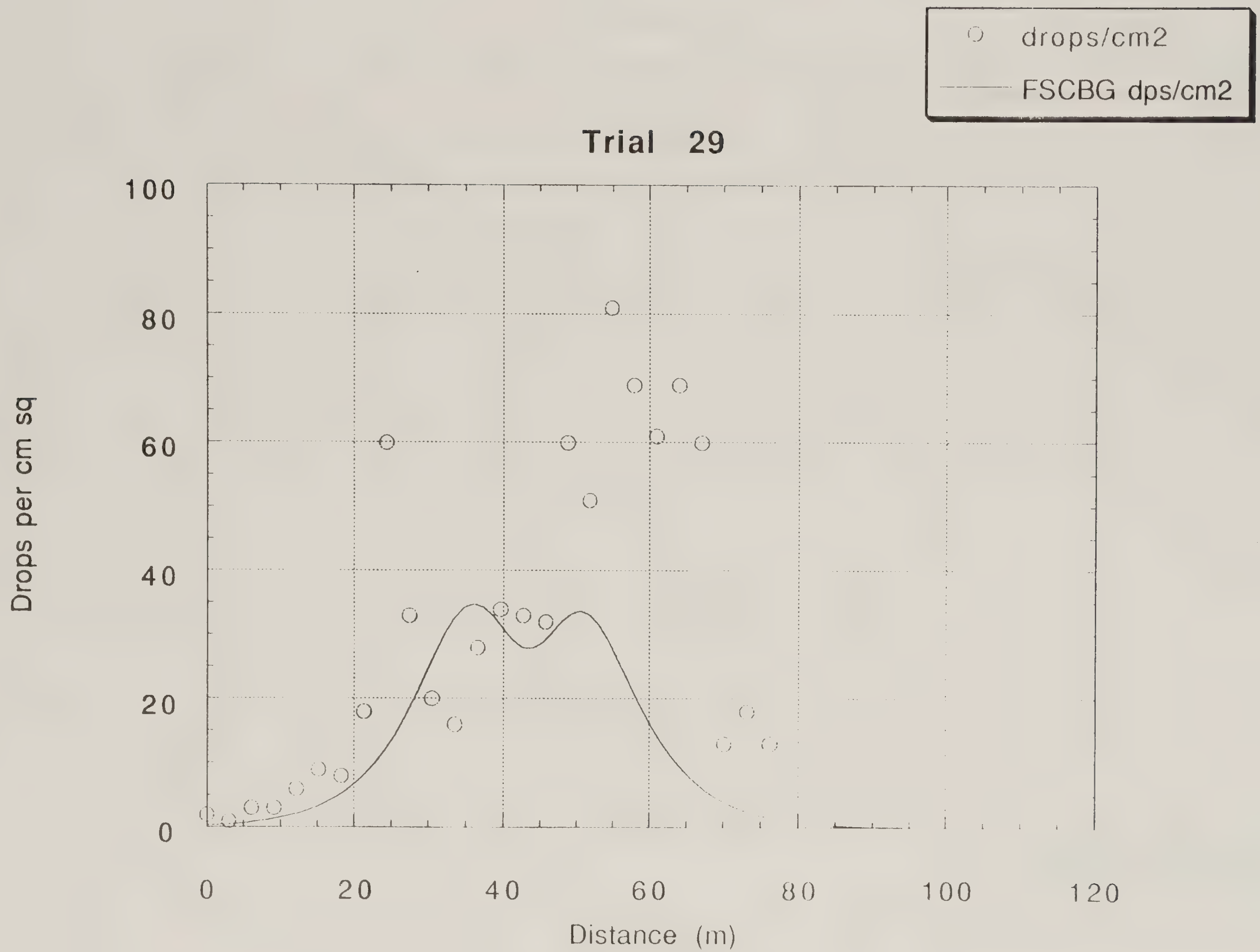


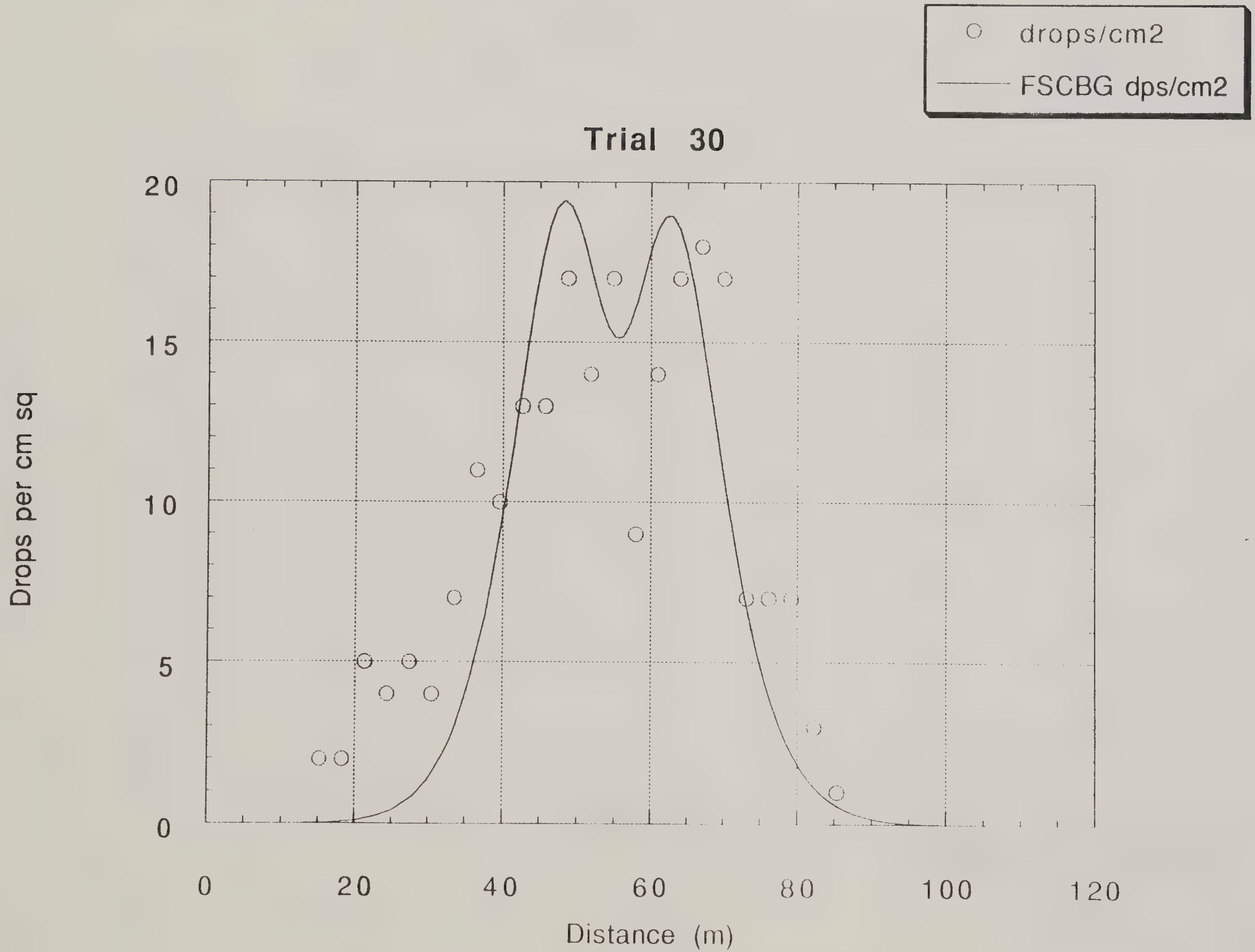
drops/cm2
FSCBG dps/cm2
20
15
10
5
0
Drops per cm sq
0
50
100
150
200
Distance (m)



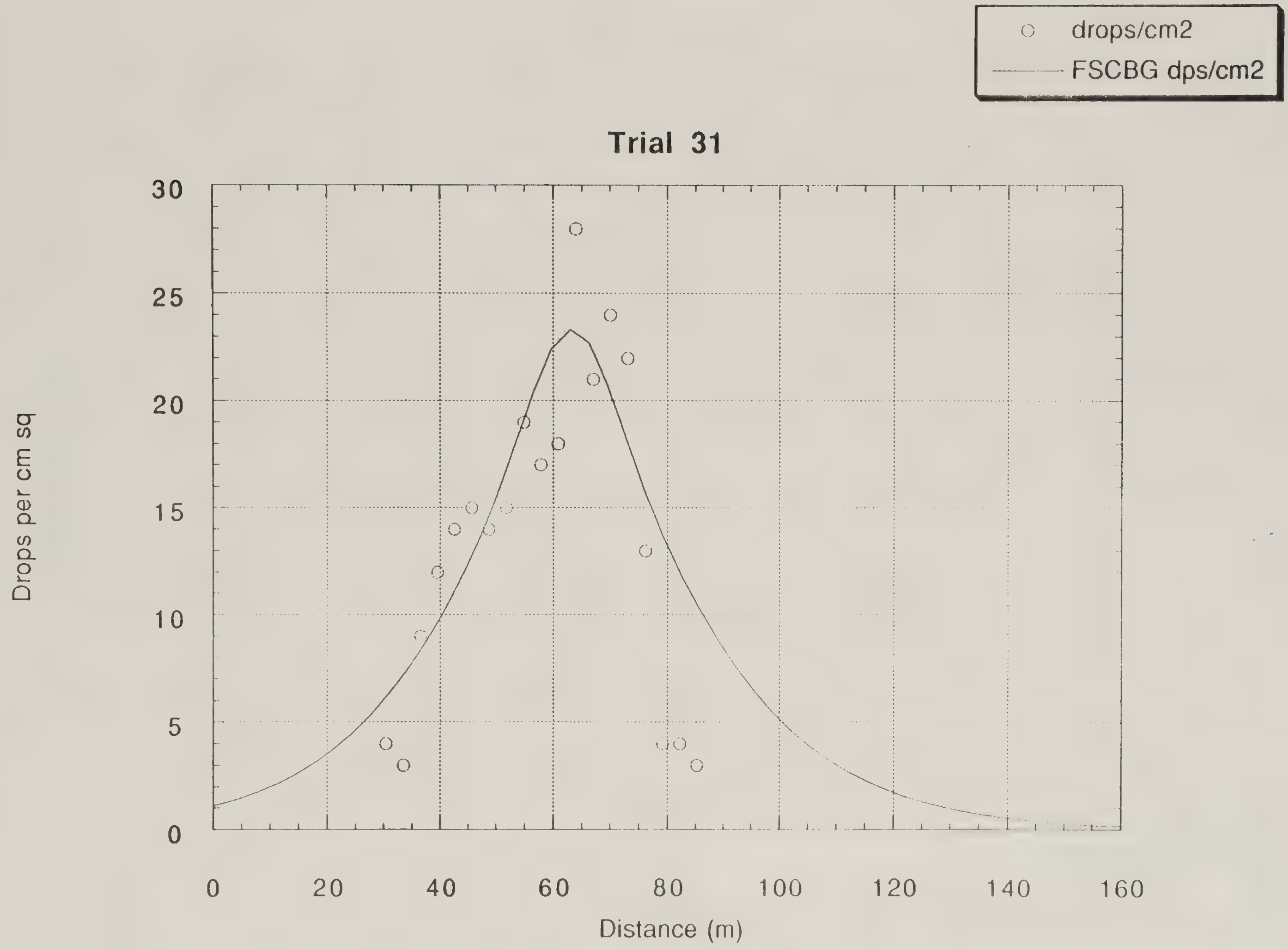
drops/cm2
FSCBG dps/cm2
Trial 27
15
10
5
0
0
20
40
60
80
100
120
140
160
Distance (m)
Drops per cm sq


drops/cm2
FSCBG dps/cm2
Trial 28
25
20
15
10
5
0
Drops per cm sq
0
20
40
60
80
100
120
Distance (m)

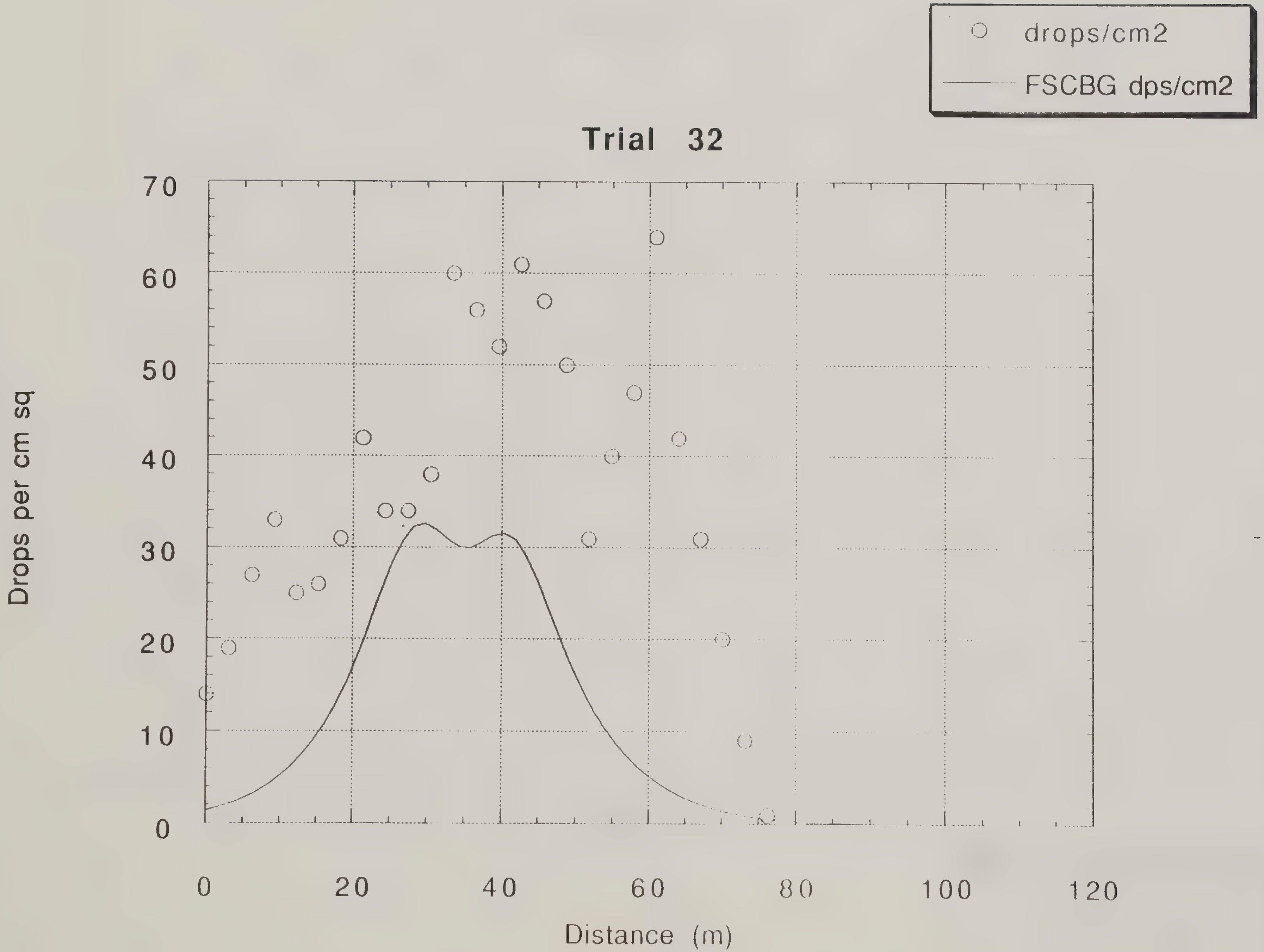

drops/cm2
FSCBG dps/cm2
Trial 29
100
80
60
40
20
0
Drops per cm sq
0
20
40
60
80
100
120
Distance (m)

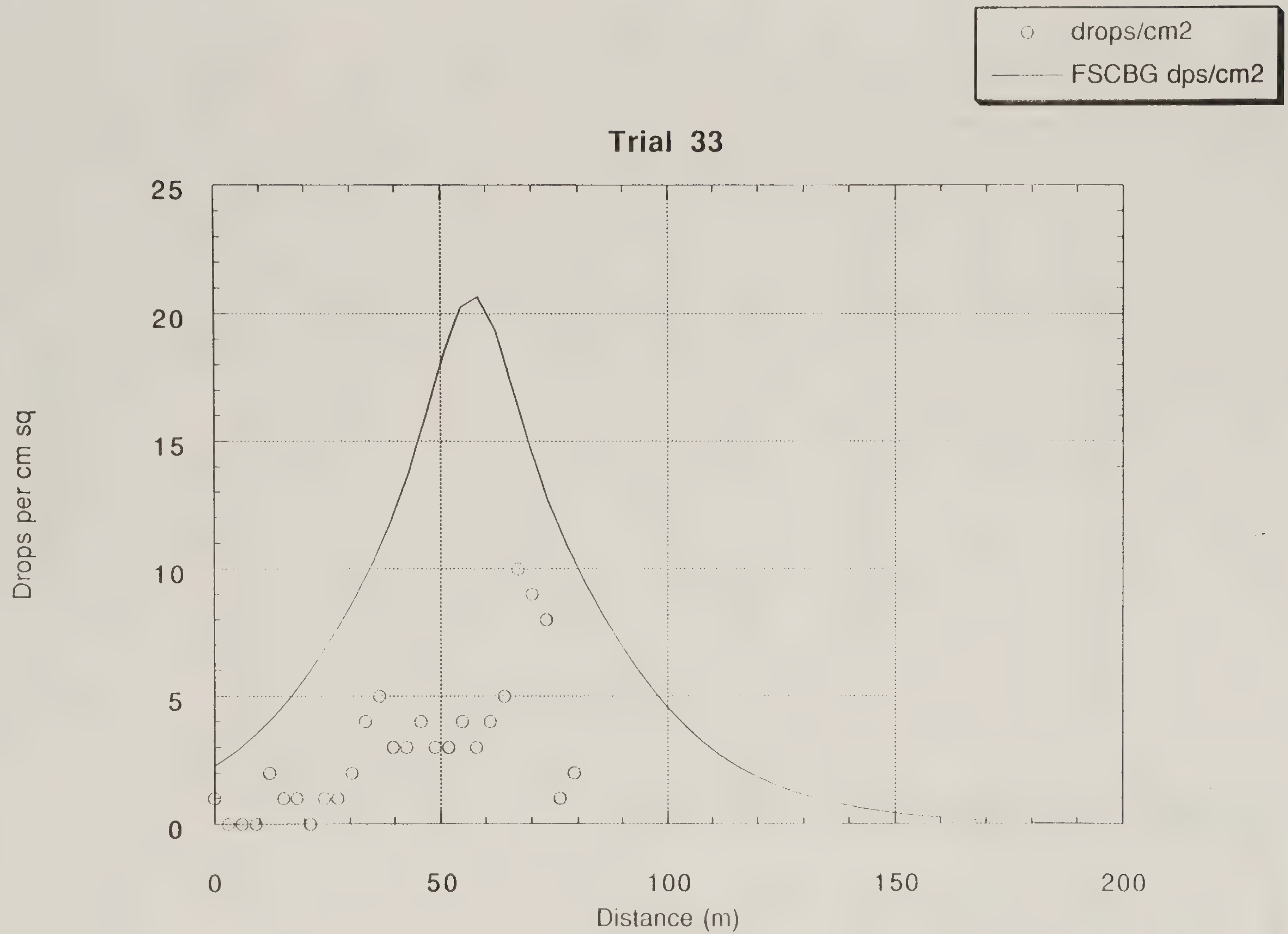


drops/cm2
FSCBG dps/cm2
Trial 30
20
15
10
5
0
0
20
40
60
80
100
120
Distance (m)
Drops per cm sq

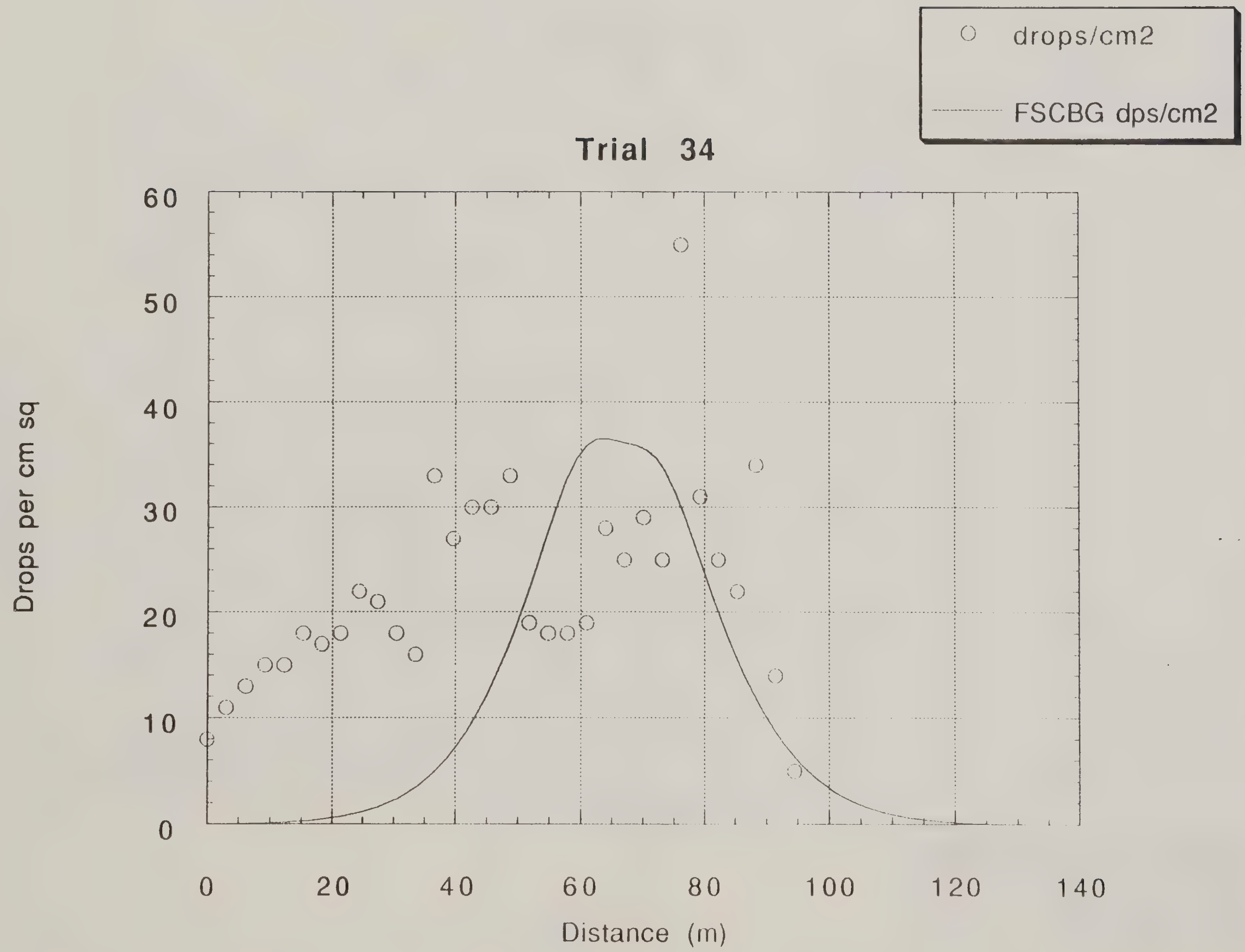


drops/cm2
FSCBG dps/cm2
Trial 31
Drops per cm sq
30
25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
Distance (m)

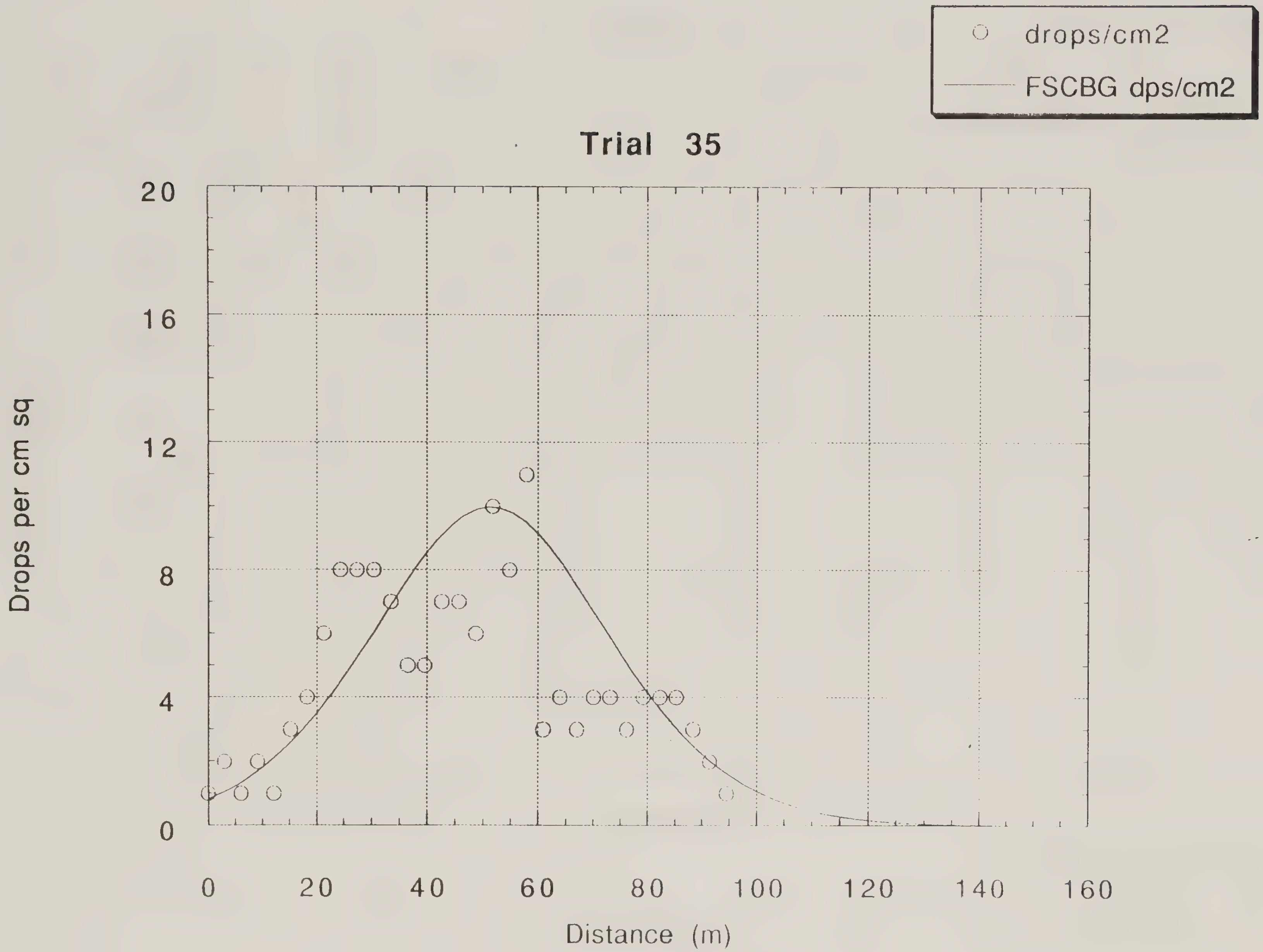

Trial 32
drops/cm2
FSCBG dps/cm2
Drops per cm sq
Distance (m)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120

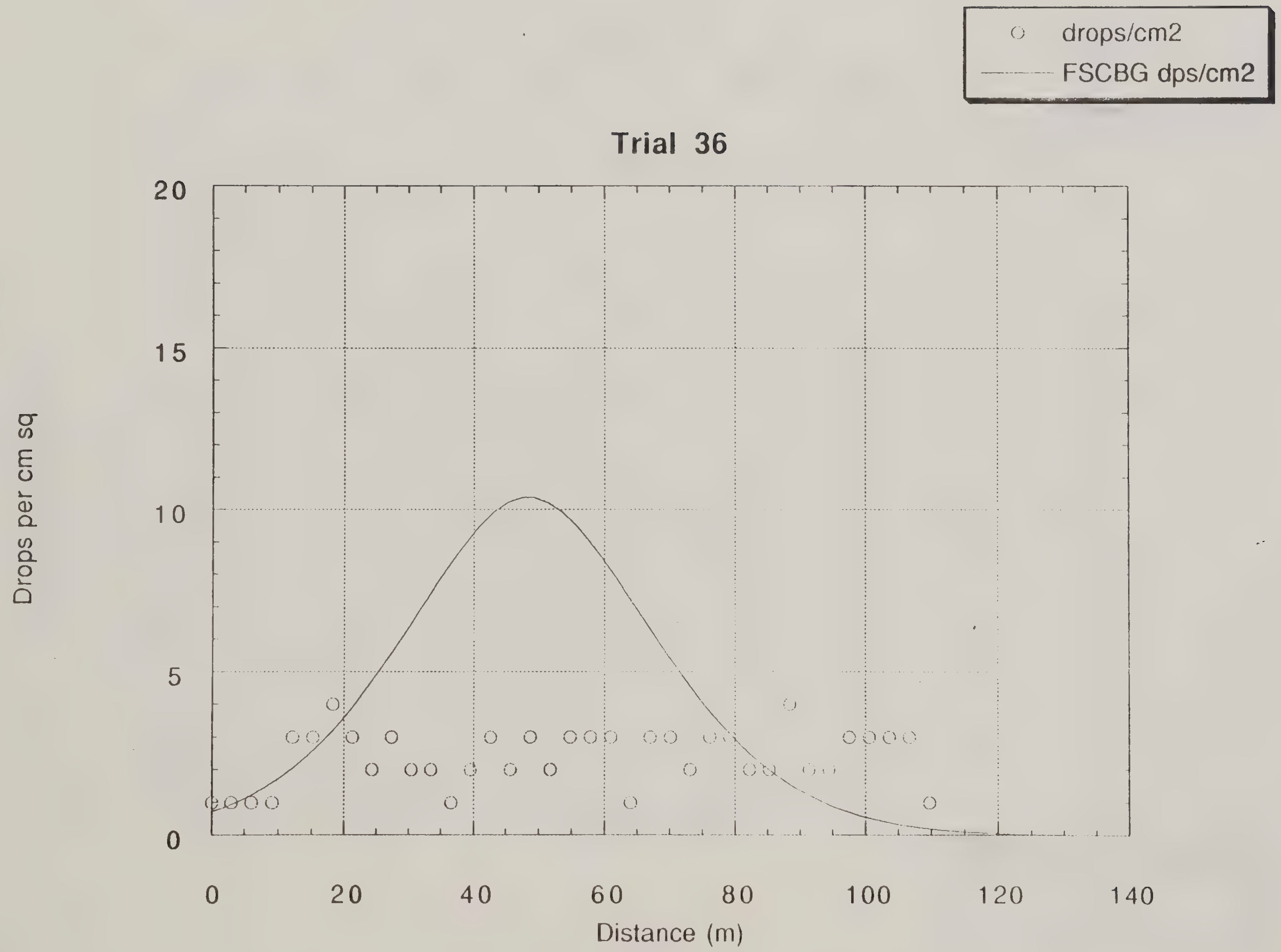


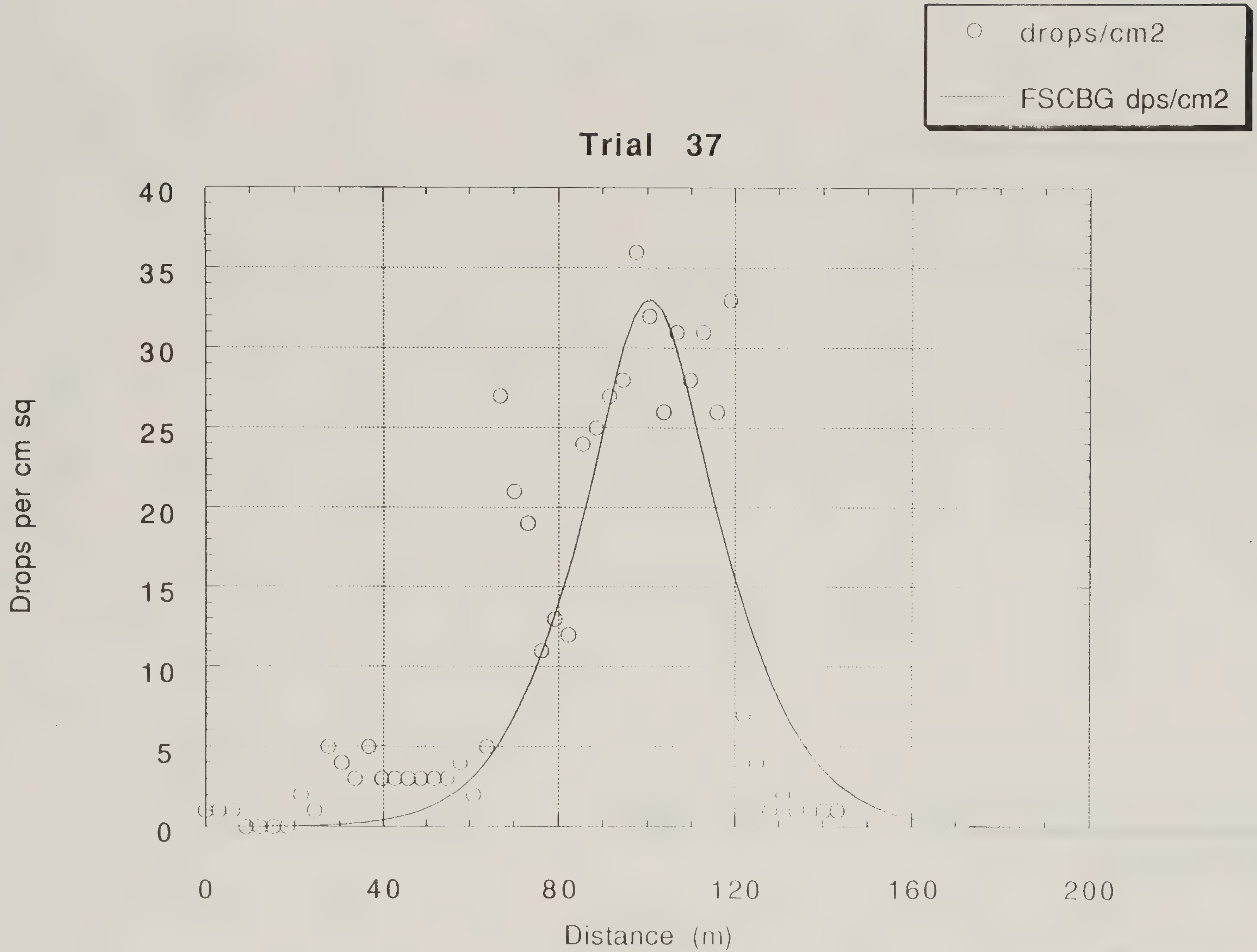
drops/cm2
FSCBG dps/cm2
Trial 33
Drops per cm sq
0
5
10
15
20
25
0
50
100
150
200
Distance (m)



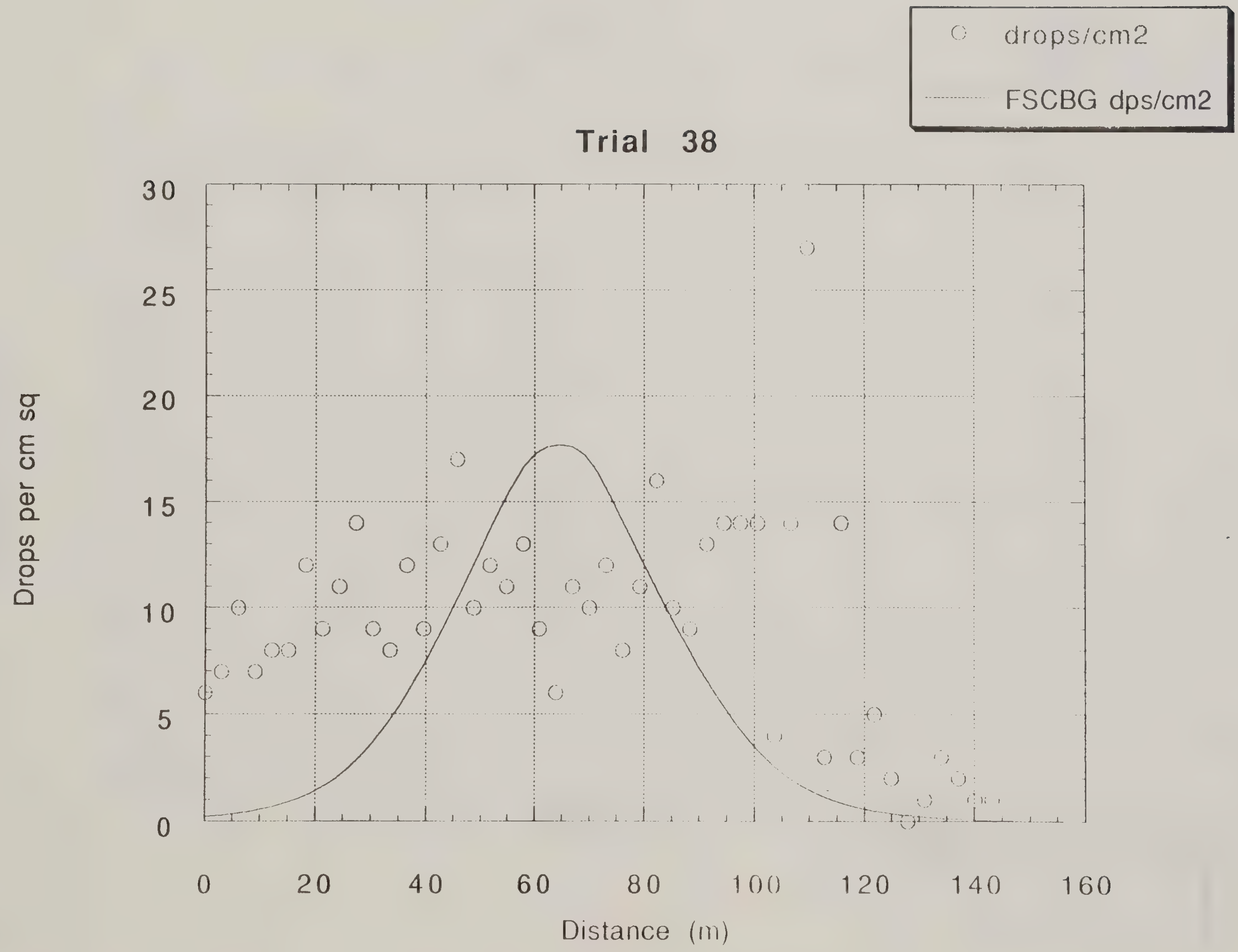
Trial 34
drops/cm2
FSCBG dps/cm2
Drops per cm sq
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
Distance (m)


drops/cm2
FSCBG dps/cm2
Trial 35
Drops per cm sq
20
16
12
8
4
0
0
20
40
60
80
100
120
140
160
Distance (m)

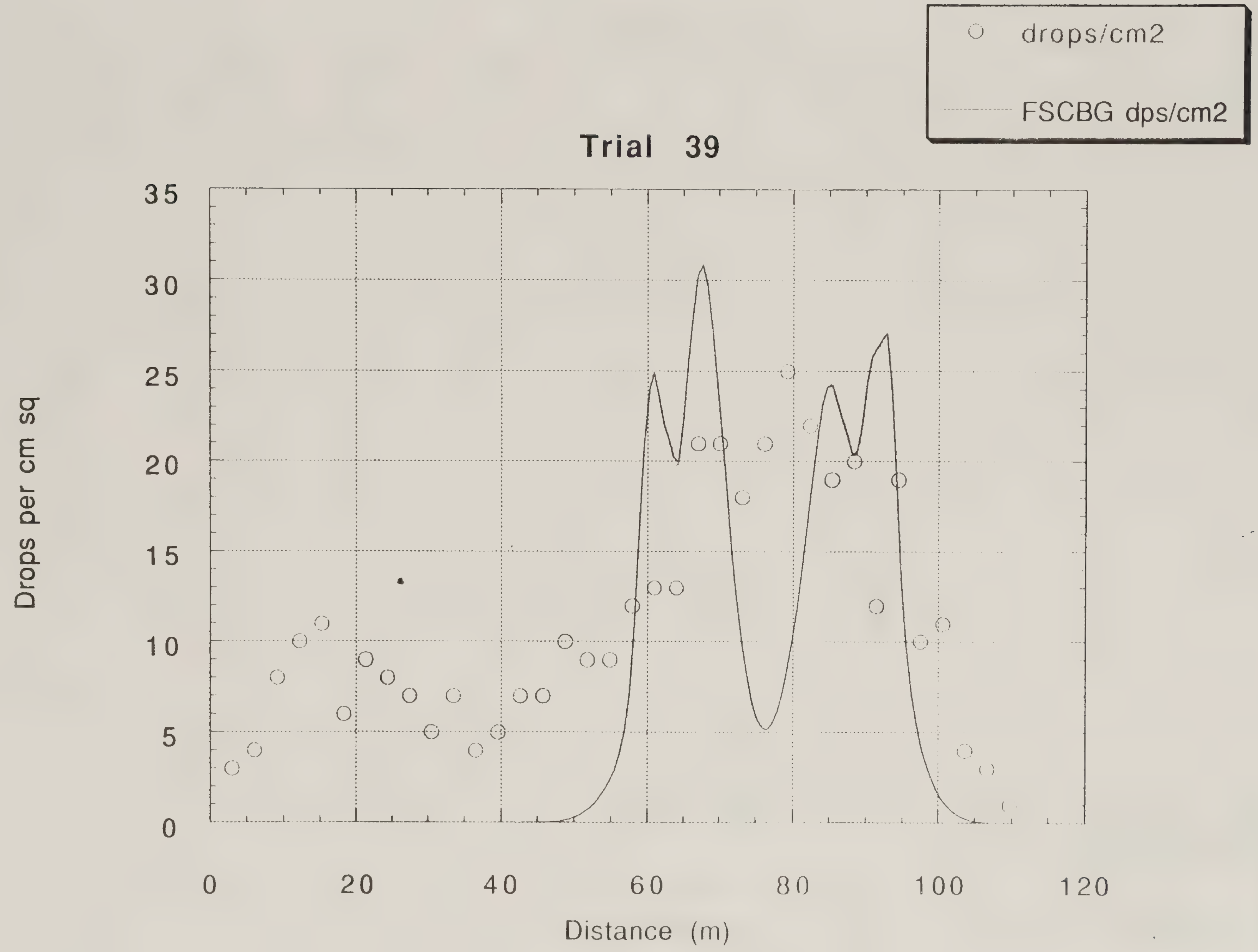

drops/cm2
FSCBG dps/cm2
Trial 36
20
15
10
5
0
0
20
40
60
80
100
120
140
Distance (m)
Drops per cm sq



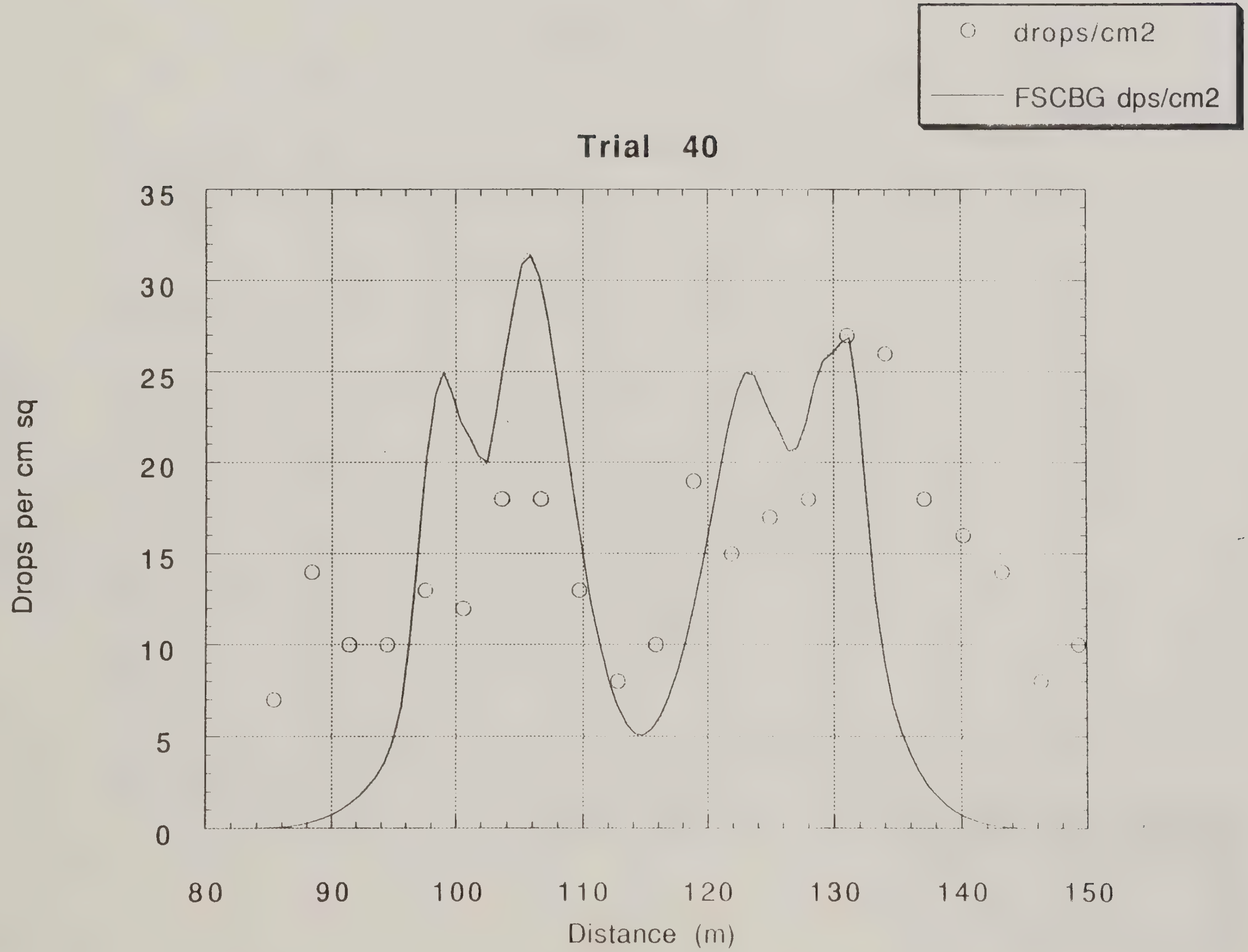
Trial 37
drops/cm2
FSCBG dps/cm2
Drops per cm sq
0
5
10
15
20
25
30
35
40
0
40
80
120
160
200
Distance (m)



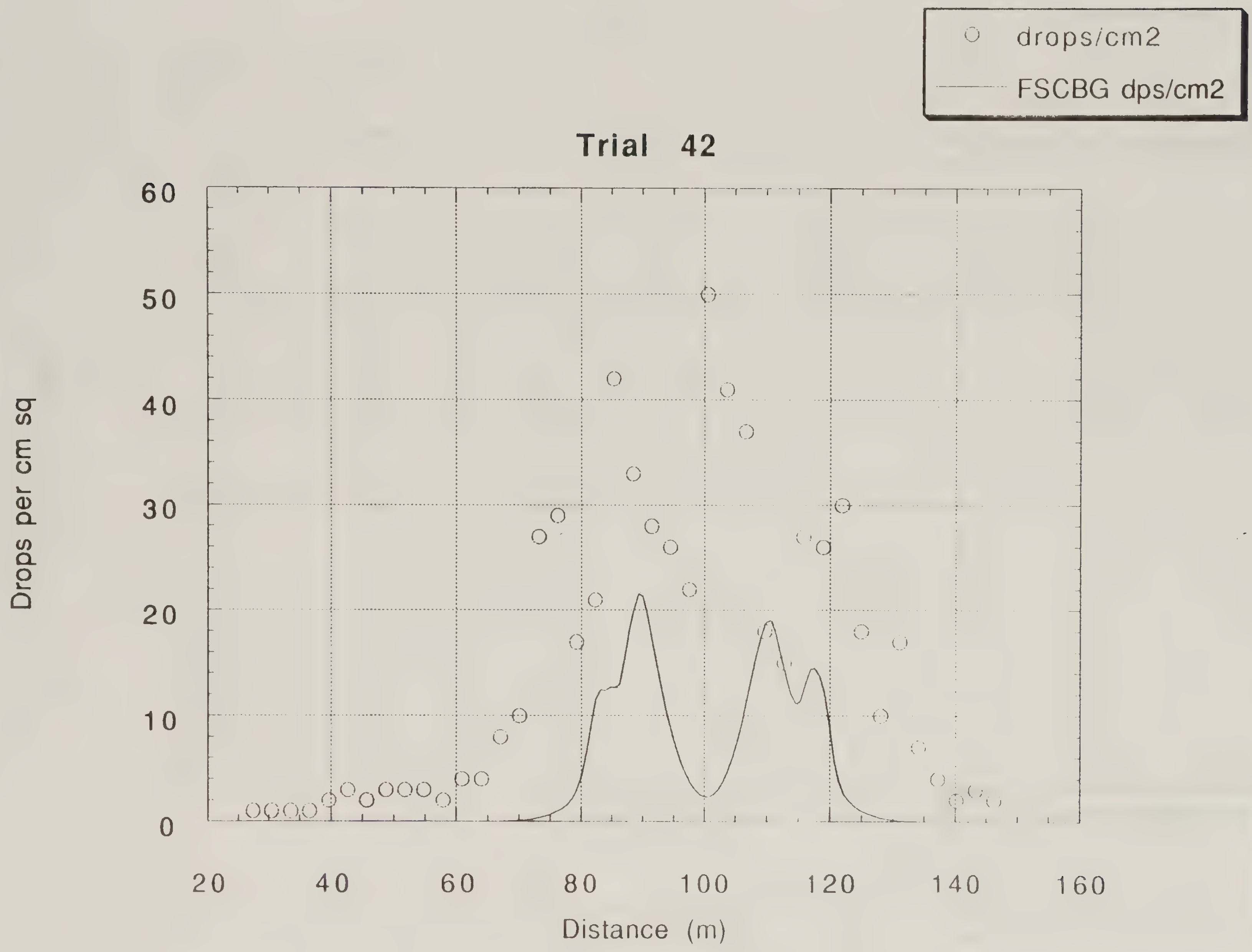
Trial 38
drops/cm2
FSCBG dps/cm2
Drops per cm sq
Distance (m)
0
20
40
60
80
100
120
140
160
0
5
10
15
20
25
30

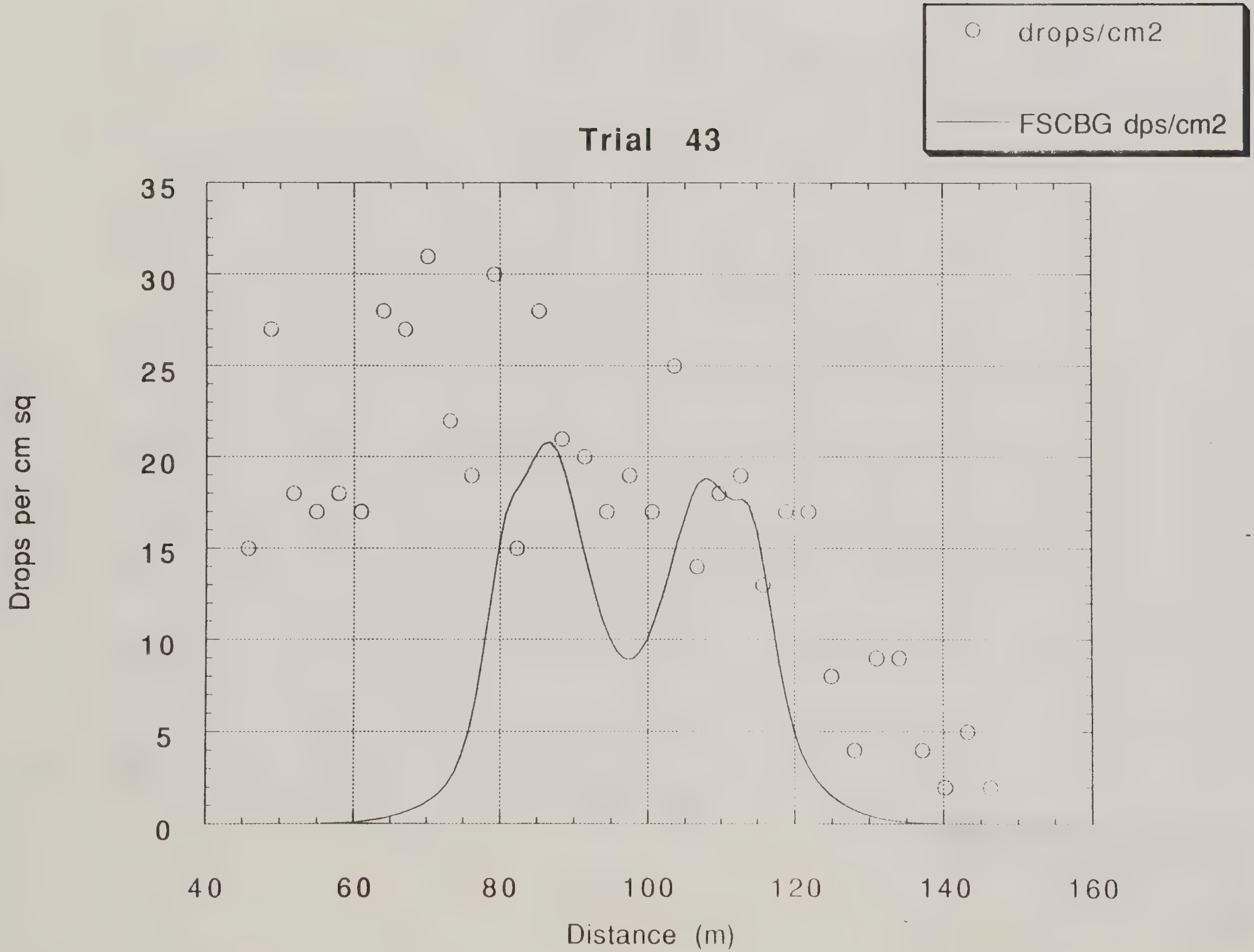


Trial 39
drops/cm2
FSCBG dps/cm2
Drops per cm sq
Distance (m)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120

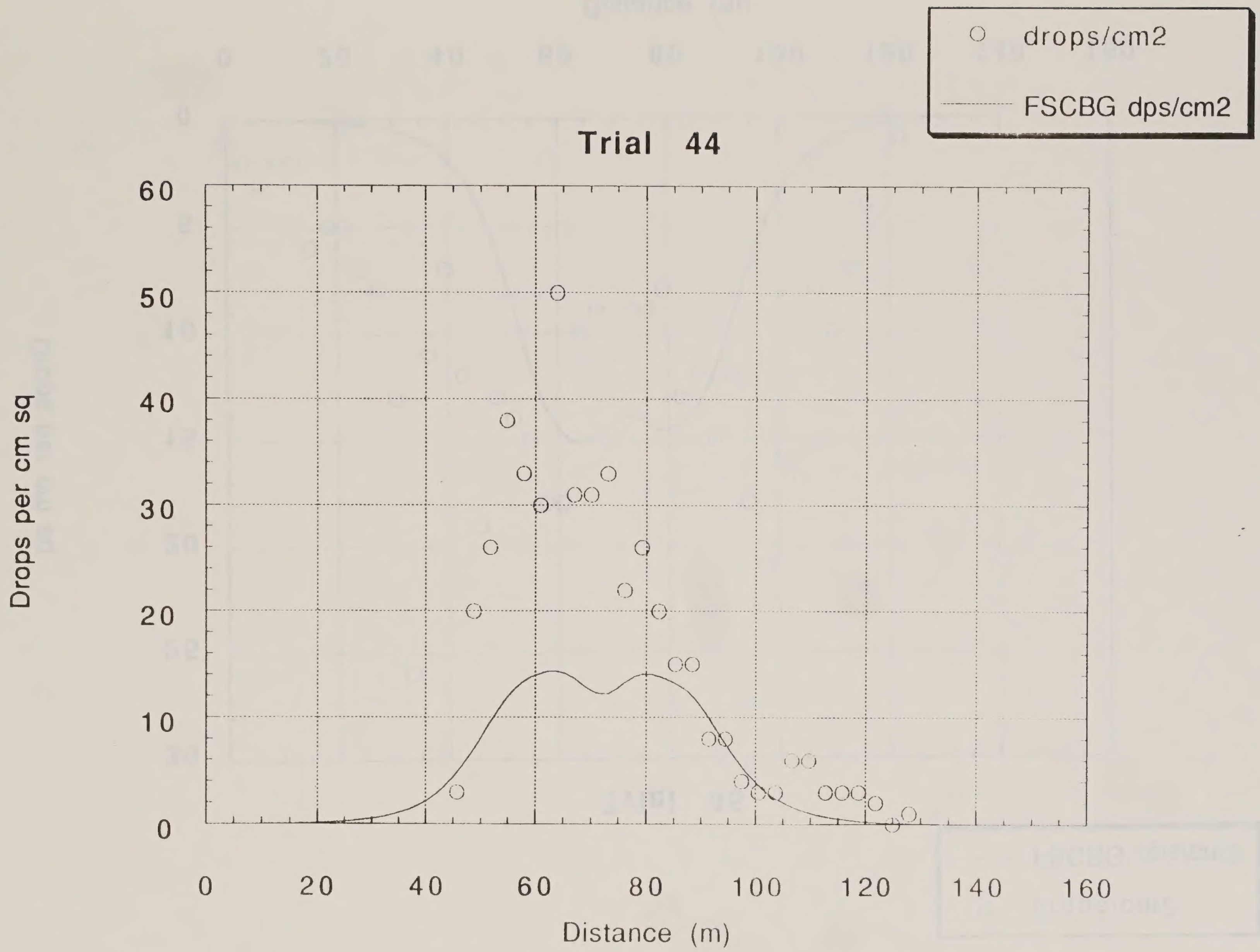


Trial 40
drops/cm2
FSCBG dps/cm2
Drops per cm sq
0
5
10
15
20
25
30
35
80
90
100
110
120
130
140
150
Distance (m)

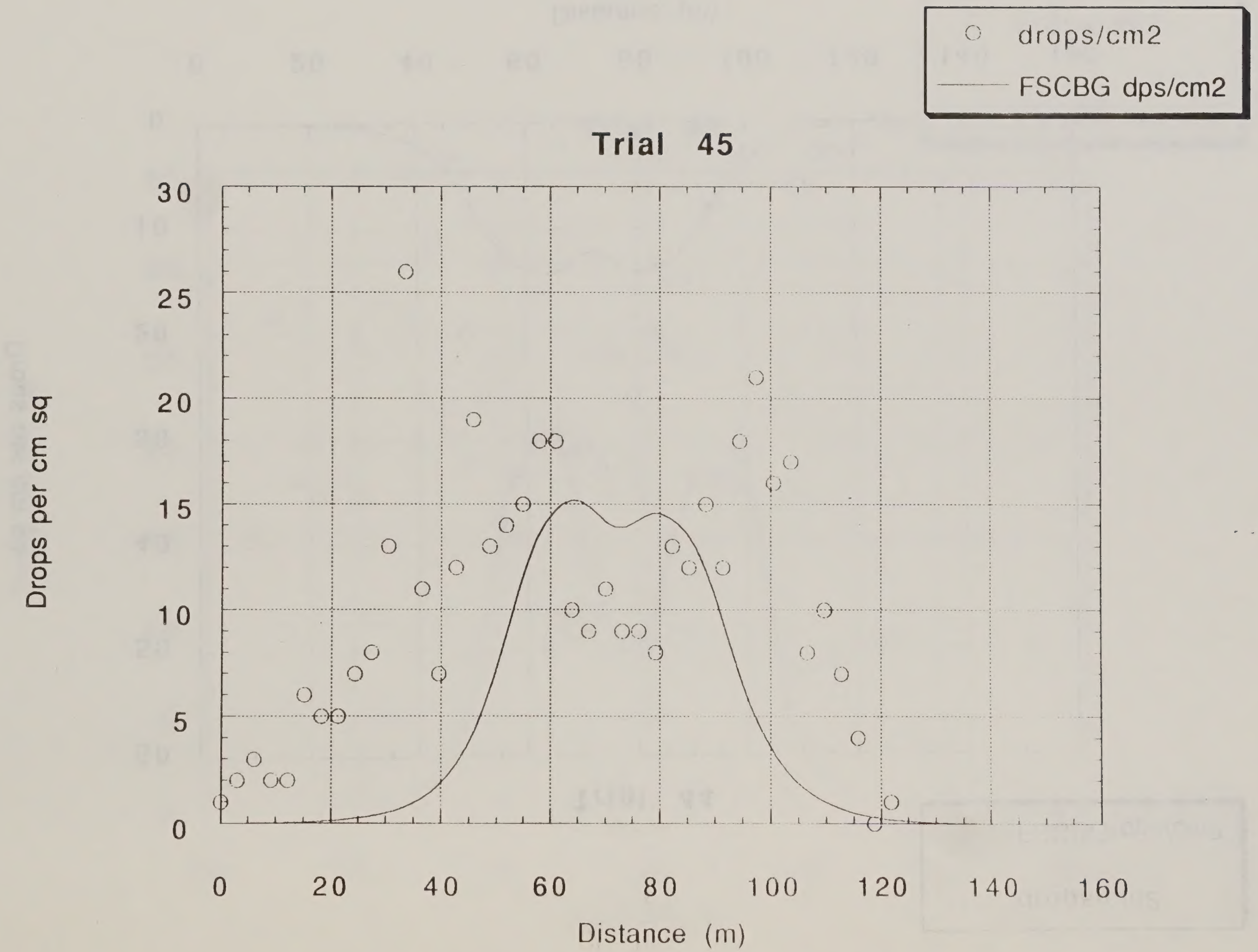

Trial 42
drops/cm2
FSCBG dps/cm2
Drops per cm sq
Distance (m)
0
10
20
30
40
50
60
20
40
60
80
100
120
140
160



Trial 43
drops/cm2
FSCBG dps/cm2
Drops per cm sq
35
30
25
20
15
10
5
0
40
60
80
100
120
140
160
Distance (m)



drops/cm2
FSCBG dps/cm2
Trial 44
Drops per cm sq
0
10
20
30
40
50
60
0
20
40
60
80
100
120
140
160
Distance (m)



drops/cm2
FSCBG dps/cm2
Trial 45
Drops per cm sq
0
5
10
15
20
25
30
0
20
40
60
80
100
120
140
160
Distance (m)